Maritime Cast Shop Integrated Improvement Plan

Contract # SP4701-08-C-0026
Final Report

Prepared for Defense Logistics Agency under the Industrial Base Innovation Fund

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Understanding future effects of today's decisions

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14. ABSTRACT
Under the auspices of the Defense Logistics Agency (DLA) Maritime Cast Shop (MCS) Integrated Improvement Plan, this project provided substantial improvements to two foundries that provide significant Department of Defense maritime products.

The Willcor Industrial Base Innovation Fund (IBIF) proposal was a result of observations made while assisting General Dynamics Electric Boat to improve their supply chain which included critical casting suppliers. Shipbuilders periodically experience construction schedule delays with resultant cost increases from castings issues. Casting issues in shipbuilding include the late delivery of components as well as the late discovery of latent quality issues. Costs of shipyard delays are typically vastly out of proportion with the actual cost of the casting itself.

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1 SUMMARY

1.1 Introduction

Under the auspices of the Defense Logistics Agency (DLA) Maritime Cast Shop (MCS) Integrated Improvement Plan, this project provided substantial improvements to two foundries that provide significant Department of Defense maritime products.

The Willcor Industrial Base Innovation Fund (IBIF) proposal was a result of observations made while assisting General Dynamics Electric Boat to improve their supply chain which included critical casting suppliers. Shipbuilders periodically experience construction schedule delays with resultant cost increases from castings issues. Casting issues in shipbuilding include the late delivery of components as well as the late discovery of latent quality issues. Costs of shipyard delays are typically vastly out of proportion with the actual cost of the casting itself.

During the conduct of previous efforts, it was noted that casting houses supporting U.S. Navy shipbuilding have several common characteristics:

- The manufacturing effort is typically high mix, low volume
- Radiographic casting upgrade processes and the subsequent defect weld upgrade, review and approval process is a cycle time driver
- The business is frequently small, often under one hundred employees
- Environmental policies discourage the development of new casting businesses or expansion of existing operation, and therefore most of the maritime foundry industrial base has been established for several decades
- The business has not made the investments to incorporate state of the art practices in;
    - Physics based finite element solidification modeling software tools
    - Technical process innovations and improvements
    - Continuous improvement techniques developed specifically to support reducing cycle time and waste in high mix, low volume manufacturing

The results of this project were exceptional. At the first MCS, the following improvements were accomplished during the course of this effort:

- 26% - 42% reduction (part number dependant) in the total number of part moves throughout the shop and reliance on bridge crane and forklifts whose availability and slow speed of operation contribute to inefficiencies
- 20% - 42% reduction (part number dependant) in the number of intra-shop Grind⇒Inspect⇒Weld⇒Inspect loops
- 20% improvement in efficiency in Upgrade and Inspection operations
- 26% reduction in work in progress (WIP)
- 28% reduction in the close out report (details all casting flaws and planned to actual labor used per casting and issues encountered) hourly rate through the quarter ended Sep 2009
- 34% capacity increase in the overall constraining department, Inspection
- 4.7% scrap reduction

An 8 week engagement at the second MCS facility was focused on improving the cycle time for their largest casting line and the following results were attained:

- 19% reduction of time taken to make their large molds and castings
- 500 square feet of floor space was freed up at the mold line for other priorities. Additional space was made available in the pattern room, core room and adjacent storeage room
- Increased throughput opportunity was identified with the addition of unskilled support

Based on benchmarking and other related work, Willcor conceived of an approach to improve foundry product lines beyond the traditional tactic of improving "one casting at a time." The proposal included four elements integrated into a program designed to improve the upgrade process and first time cast component quality:

- Job Shop Lean - reduce production lead times on short-run, low volume, castings
- Physics Based Software Tools – off the shelf technology to improve mold design
- Technical Processes Assessment – deploy industry best practice technologies
- Computed Radiography – digital files to replace costly film and improve cycle time

Significant progress was made on these tasks with the exception of Computed Radiography. The delay of approval by Naval Sea Systems Command (NAVSEA) of standards for the application of Computed Radiography on nuclear, Level I and SUBSAFE components, the primary products of this foundry, made the execution of this task problematic. (Note: One foundry has decided to buy Computed Radiography equipment for preliminary quality and information shots. The forward leaning thinking of this foundry will place it at the forefront of Computed Radiography use once these standards are approved.)

The success criteria for this project was the number of recommendations or projects successfully "transitioned" into daily operations by the MCS. The Maritime Cast Shop Integrated Improvement Project resulted in the implementation of numerous plant flow changes and technologies with significant investments made by the MCS, all of which have contributed to significant improvements in the manufacture of cast components and the reduction of schedule and cost risk to submarine, aircraft carrier and amphibious ship construction shipyards.

The paragraphs below provide a summary of results obtained. In depth analysis and discussion of the results at the two foundries are part of the reports included as attachments A and B.

1.2 MCS 1

1.2.1 SUMMARY, RESULTS OBTAINED AND CONCLUSIONS

1.2.1.1 Job Shop Lean

Typical lead times for maritime sector valve bodies are about 30 weeks. Larger castings such as hatches and hull trunks are typically double this lead time. A cladding process applied to a cast component can have lead times that approach two years. Job Shop Lean (JS Lean) has successfully reduced similar lead times when applied by the DLA R&D Enterprise Team (DLA-J339) and the Logistics R&D Branch (DLA-DSCP) to forges in the aviation and land sectors. The Willcor team successfully applied JS Lean techniques to maritime sector foundries during the course of this work.

The MCS upgrade facility (Upgrade) and foundry (Cast shop) are true job shops; they both contain a number of “monuments” and job-to-job variation demands a high degree of flexibility on the shop floor. The foundry and weld upgrade facility are integral parts of the value stream. Upgrade is integral to the nuclear, Level I and SUBSAFE maritime foundry castings and determines about 65-85% of product lead time.

The primary goal of this task was to reduce the average cycle time for castings that are processed in the upgrade facility. Second tier objectives which supported the primary goal were:

- To reduce the total time spent to complete weld/grind/inspect cycles for emergent repair on the castings
- To improve work-flow and reduce Work in Process (WIP) by improving the storage, control of workstation queues, and improving scheduling and tracking of active orders
- To identify and improve production constraints and bottlenecks
- To increase value-added utilization of resources in the work cells identified as constraints

During early efforts the Inspection Department was identified as a critical constraint which, along with other intra-shop transportation and handling, contributed to a large amount of WIP present on the shop floor.

- To achieve these goals and objectives, specific projects undertaken were: Implementation of a manufacturing cell and associated area layout improvements which reduced casting transportation and handling.
- Implementation of a scheduling system between the constraint department (Inspection) and the non-constraint departments (Grinding, Welding and Radiography.)
- Improvements in the Inspection Department (constraint department) layout, supporting tool access/organization, which improves overall plant throughput.
- Analysis and identification of ways to improve throughput in shipping and receiving which was co-located with inspection.

Initial focus was placed on improving the overall plant constraint, which was inspection capacity. The Team initially found over production at several work centers in the upgrade facility. Inspection did not have the capacity necessary to increase throughput and therefore reduce cycle and lead time. Theory of constraint methods were applied to this bottle-neck and the team achieved a throughput increase of 34% at inspection.

Based on analysis of a sampling of casting patterns, the MCS decided to implement a cell that would co-locate workstations for Grinding and Welding. The capability for grinding or welding technicians to perform self inspection using portable Magnetic Particle Inspection hand held units was also developed. This provides technicians the ability to self-inspect and reduces the number of surface defects found at the final ‘buy off’ formal inspection. The following benefits are realized with implementation of this cell:

- 26% - 42% reduction (part number dependant) in the total number of part moves throughout the shop and reliance on bridge crane and forklifts whose availability and slow speed of operation contribute to inefficiencies

- 20% - 42% reduction (part number dependant) in the number of intra-shop Grind⇒Inspect⇒Weld⇒Inspect loops

Personnel and resource limitations at the MCS required implementation of cell improvements to be accomplished in phases. Phase 1 is complete and additional phases are in planning.

Key company measures over the most recent six months (June-November 2009) of this project demonstrate the impact of the plant floor improvements described in subsequent sections:

- 20% improvement in efficiency in Upgrade and Inspection
- 26% reduction in work in progress (WIP)
- 28% reduction in the close out report (report shows planned to actual labor element per casting and any problems encountered) hourly rate through the quarter ended Sep 2009
- 34% Capacity increase in the overall constraining department, Inspection
- 4.7% scrap reduction from the same timeframe of the previous year

Theory of Constraints methods were applied which reduced WIP, an indicator of increased throughput through the plant and Inspection constraint. Increasing Inspector's "value added" inspection time by 34% provided concrete evidence of additional capacity gains in the plant constraint. This improvement reduces cycle time and overall lead times of the castings, a key goal of the project. Improved quality of castings, another goal of the overall project, also contributes to reduced WIP as this causes less work content in Upgrade. Scrap rate trends during this six months show a 4.7% reduction from the same timeframe of the previous year.

Improved productivity measures such as reduced labor hours as a percentage of sales are being observed. This observation demonstrates success in removing non-value added activity in the Upgrade and Inspection processes. Initial casting quality also appears to be improving based on the company's recent casting close out reports. These reports provide data on work performance against planned hours and detail casting flaws found and addressed. In a recent set of about forty close-out reports only one casting exceeded planning estimates.

1.2.1.1.1 Conclusions

Job Shop Lean has proven to be a flexible and adaptable methodology that is equally successful in the MCS foundry as it was in prior DLA forge applications. The MCS foundry and associated upgrade facility has improved in a number of critical areas as demonstrated by improving company measures which indicate capacity/throughput has been increased, which in turn reduces the lead time of critical maritime castings. JS Lean has proven to be an excellent precursor to other technically focused foundry process improvement methods.

1.2.1.1.2 Lessons Learned

PROCESS MAPPING

It is recommended that process mapping (and value stream mapping) which identifies areas of waste and improvement opportunity areas precede efforts focused on the foundry technical process. Process mapping helps the technology focused efforts get off to a faster start as the entire process has already been mapped out and viewed from a holistic "system" level. The methods/tools used in JS Lean and quality improvement efforts have many similarities and are often synergistic. Group technology approaches which are a cornerstone of JS Lean are an important starting point in a custom foundry such as this that has a high mix/low volume business or product base. The WILLCOR Team believes that the hands on approach taken with an engineer or engineer intern (with appropriate JS Lean training and ongoing mentoring) working onsite with the company accelerated the pace of adoption of the methods and improvements. Strong involvement and coaching of managers by the company President/CEO is essential to achieving the rapid success MCS has seen to date.

CUSTOMER DRIVEN HOLD POINTS

An ancillary issue observed at the MCS and by the WILLCOR team at many other component manufacturers is the untimely accomplishment of customer required hold points. Customer required hold points are essential elements of the customer's supply chain quality assurance plan. These hold point requirements should not be diminished but should be better managed.

The untimely accomplishment of customer required hold points cause components to be stored as work in progress until the customer can accomplish the inspection. As with any WIP, cost and lead time is increased and instability in schedules is created.

It is incumbent on the shipbuilding industry to recognize this issue and take steps to mitigate its impact.

1.2.1.2 Physics Based Solidification and Computer Aided Drawing (CAD) Software Tools

During the Assessment phase, the WILLCOR team worked with the foundry managers and senior trade personnel to develop the information relevant to implement physics based software tools and 3-D modeling capability.

The Willcor Team developed an incremental plan to build aptitudes and skills necessary to deploy 21st Century software tool implementation. The plan identified and enabled the ability to develop critical knowledge and capabilities essential for the successful deployment of commercially available physics based solidification tools. The critical steps identified were:

- Identify MCS personnel with credentials and background suitable to learning and using sophisticated engineering software tools
- Train MCS personnel in the use of 3-D CAD software tools supported by physics based solidification suites
- Put the 3-D CAD software into regular use in the mold engineering processes
- Develop the ability to use the 3-D CAD software as the foundation of the development of Computer Numerically Controlled (CNC) machine code for the manufacture of patterns
- Train the MCS personnel in the use of a commercially available physics based solidification software suite
- Validate the physics based solidification software in the cast shop though the use of test pouring
- Make process changes
    - Bidding and marketing operations request digital renderings of cast components
    - Integrate software tools into the core operations of the cast shop and the marketing operation

After reviewing this task, MCS management decided in March that the costs and resources associated with conducting this task would be large and might not be offset by savings over the typical small quantity production runs. As such, it was decided that the immediate implementation of the physics based software tools was not feasible based on present realities of the cast shop operations. All other elements of this task such as the training in CAD tools were conducted. To support activities in this area, the MCS hired an engineer with appropriate computer bona fides. Key cast shop personnel joined Willcor Subject Matter Experts to form a team to execute activities that would enable the 3-D modeling capability.

1.2.1.3 Results

To familiarize the new-hire engineer with casting operations, the team developed a process map for the cast shop. This dual use document was employed as a training aid as well as an overview of operations for the targeting of process improvements, discussed in the next section.

The new-hire engineer had basic knowledge of the 3-D CAD SOLIDWORKS software package and initiated use of this tool to generate digital renditions of patterns. MCS engineers attended training provide by TRIMECH Solutions, an authorized reseller of the SOLIDWORKS software. The foundry then used the SOLIDWORKS software tool to generate digital renditions of patterns.

Both the MCS marketing personnel and the Willcor SME requested digital renditions of cast components to facilitate the use of 3-D CAD software. Customers were either unable or reluctant to provide digital renditions of components.

The MCS has, on a limited basis, started contracting for solidification studies of their more difficult or problematic castings by a third party source. The third party used the 3-D CAD drawings produced by the MCS and evaluated mold design using physics based solidification software. The MCS use of the third party evaluations has so far produced successful castings on two occasions.

The MCS has also stated they would use the 3-D CAD drawings to explore the use of CNC routines with their suppliers.

The MCS ultimately decided not to conduct this task as originally proposed due to concerns of overloading the staff and questions surrounding the return on a substantial investment given the small production runs of each mold modeled. The task was partially completed and successful in that MCS hired an engineer with basic CAD tool skills that were enhanced through training. This placed MCS in a position to use Physics based tools on their more challenging castings with an a third party provider on an as needed basis and positioned themselves to develop the capability in the future if determined cost effective.

1.2.1.3.1 Lessons Learned

A methodology or partnership approach needs to be developed that would support making the business case for a foundry to justify purchasing and use of these mature yet expensive tool capabilities. Elements of this methodology would include investments in CAD renderings by the design house (shipyards have not yet provided electronic CAD design in this case), and training an engineer or technician to use the CAD and solidification modeling tools. If, as in this case, a business case can not be established, then outsourcing of part of the work or forming a consortium to share the fixed costs may be the appropriate alternatives.

Shipyards and 1st tier shipyard suppliers need to share digital renderings of components with foundries. For several decades, shipyards and 1st tier suppliers have used software packages such as CATIA for overall ship design. These ship design software packages require digital renditions of valve bodies and other components. Component manufacturers require digital renditions to generate CNC routines. Making these items available to foundries will facilitate the use of 3–D CAD drawings in the foundry environment, minimize the cost of pattern manufacture, and facilitate the use of physics based solidification packages.

1.2.1.4 Technical Process Assessment

The MCS produces quality castings for markets that accept only the best available cast parts for use in the most critical, nuclear, Level I and SUBSAFE, applications. Observations from visits to the MCS cast operation and upgrade facilities show that high quality products are being manufactured and shipped.

The goal of this operation must be to make defect-free castings; the first time and every time. The careful selection and application of commercially available off-the-shelf technologies and training will improve first time quality of as-cast components and facilitate meeting customer specifications without extensive upgrade activities.

Production of castings with surface and/or internal flaws requires the defects be identified by inspection, ground-out, occasionally weld repaired, and inspected again. Typically, this is an iterative process. Lack of 1st time quality can be responsible for significant amounts of process time and production costs. It is a well established principle that it is not possible to inspect in quality.

In the Melt Shop, all procedures must be written and followed for every casting produced to ensure the consistency of process. Melting alloys requires that chemical compositions are to specifications and, as importantly, furnace operations and practices must be replicated each time a heat is made. Molding and casting procedures must also be adhered to for every part that is cast. To support failure analysis and quality record keeping functions, appropriate data must be recorded and archived.

The MCS cast shop operation produces a wide variety of alloys, including steels, stainless steels and cupronickels, in a wide variety of sizes. This exacerbates process control compared to a foundry that produces the same grade of steel day after day which is cast it into similar sized molds. The changes recommended in this report, especially those that are procedural, are for the purpose of creating processes that can be duplicated irrespective of the alloy being melted and cast. It can not be over emphasized that each alloy has its own metallurgical properties and the procedures used to produce it are specific for that material, and the written instructions for that grade of alloy must be satisfied.

A critical improvement is the frequent and accurate measurement of temperature. Temperature control is important to achieve the desired chemical composition and to consistently produce the technically acceptable castings. Weights of charges, amounts added, the quantity of material in the furnace or AOD vessel are essential because the rates of reaction are dependent on composition, temperature and time.

The following recommendations made were primarily procedural and require a minimum amount of capital expenditure. Adoption of the recommended practices and providing additional training to both managing and operating personnel should produce benefits in product quality and delivery.

- Purchase optical infrared pyrometers. A high temperature range to unit for measurements in the 3000^{o} F range and a low temperature range instrument for measuring temperatures less than 1000^{o} F.
- Evaluate commercially available crane scales for suitable for use in conjunction with ladles containing molten metal. A heat shield is required to protect the electronics in the scales.
- Establish a mold heating station using existing mold heating ovens to pre-heat to approximately 250F molds after closing and prior to setting them in place for casting. After proof of the utility of mold heating, explore other commercial mold heating solutions capable of heating multiple molds to supplement the existing ovens.
- Establish melt shop practices and written procedures that will determine actual weights and chemical analysis of revert. Establish a routine that will consume all scrap and revert at the same rate that it is generated to prevent accumulation and the building of inventory. Utilize the maximum amount of revert material to make up all furnace charges instead of using raw materials, such as punchings, which must be purchased and added. Punchings add new dollars to the melt costs whereas revert has already been purchased and is essentially "free" material in the charge.
- Provide additional training in the metallurgy and physical chemistry of the Induction Melting furnace and the AOD vessel to management and operating personnel. Praxair is a source of this service on the operation of the AOD vessel as well as the reactions that occur in the vessel. Instruction on the theory/practice of the Induction furnace can be taught by a qualified metallurgist
- Observations and recommendations were provided in the following areas:
  - Operation Sheet development
  - Process conformance quality
  - Casting Foundry Floor Observations
  - Finishing Operations Foundry Floor Observations

Personnel and expertise were provided to coordinate recommended changes with the following results

1.2.1.4.1 Results

Optical Pyrometers – Contact pyrometers were determined not to be a viable option for this application. Two brands of pyrometers were used on a trial basis. Neither brand was successful. Both the accuracy and the precision of instruments came into question. The MCS used two distinct pyrometer types, the first type measured the intensity of the infrared emission. The accuracy and precision of the intensity style of parameter will be significantly affected by the smoke and particulate associated with a pour and was rejected. The second type of instrument was a 'two-color' device that is not affected by smoke and particulate. Operations with the 'two color' device still resulted in problems with accuracy and precision.

The cast shop uses a bottom pour ladle for teeming molds. On further study, it was determined that mechanics of the bottom pour requires personnel to continually move around the mold and ladle. Signal interference caused by this personnel movement caused the two-color pyrometer to have accuracy and precision issues. The use of a pyrometer is considered essential for process control and failure analysis efforts and the Willcor Team recognizes that a solution which works for this application is still required.

Scales for in process weight determinations – The MCS is actively pursuing this technology. They have experienced issues with the size of the scale and heat shield. The ladle and associated crane that services the Induction Melt Furnace have space limitations that have made the purchase of a scale with appropriate heat shield problematic. The MCS is continuing to pursue solutions for this.

Mold Heaters were installed in late-November on a trial basis. The MCS reported that their first use of these items was successful. In mid-December, the Willcor Team traveled to the Propeller Foundry in Philadelphia Pa where these items were demonstrated. Successful pours using this technology were accomplished in late November and early December.

A one day training course conducted by Praxair experts was accomplished. Attendees included cast shop management team as well as the melt work station personnel.

1.2.1.4.2 Lessons Learned

The Willcor Team developed an understanding of the special issues surrounding a bottom pour operation. Work needs to be accomplished to develop these ideas into a set of best practices.

Many sources of technical help and advice exist for the foundry industry. Searches of references did not find a comprehensive foundry specific “maturity model” which a foundry could use for self assessment of key process areas or a buyer of foundry products could use to benchmark a foundry operation.

1.2.1.5 Computed (Digital) Radiography (CR)

NAVSEA standards for CR of Nuclear, Level I and SUBSAFE systems were not completed as anticipated for this task. The Team decided not to pursue this task due to lack of necessary customer standards. The MCS has recently procured the Virtual Media Integration CR equipment for “informational quality” shots, as opposed to formal customer buyoff. These capital purchases enable the organization to be well positioned for the future

1.3 MCS 2 - SLF

1.3.1 Introduction

The Maritime Cast Shop Integrated Improvement project was planned as a project to address maritime foundry issues at a single MCS. This second maritime foundry project was initiated after discussion with DLA to add additional value to the DoD customers of maritime castings which are typically long lead items. After discussions with the ship clutch and brake supplier, Eaton Airflex and Stateline Foundries (SLF), a focused effort consisting primarily of Job Shop Lean efforts and an assessment of foundry processes by a foundry expert was planned. The goal was to provide off-the-shelf cost effective tasks that would lead to improved 1st time casting quality and reduced lead and cycle time.

SLF is a quality-driven, customer-responsive iron foundry specializing in prototype and low-to-medium volume production castings. SLF completed ISO 9001:2000 certification in November of 2002 and has in-house metallurgical testing capabilities using an in-house spectrograph and tensile testing equipment. SLF also use process controls and special instructions for each part to assure quality.

SLF produces castings ranging from ounces up to 2,000 pounds in lot sizes of one to thousands. With batch furnaces SLF pours multiple grades of gray and ductile iron each day. SLF considers the flexibility and capability to rapidly produce iron castings of various complexities, sizes and metal specifications a competitive market niche. SLF pours all grades of Gray and Ductile Iron;

* Austempered Ductile Iron
* High Temperature Ductile Iron (High Silicon Molybdenum)
* Gray and Ductile NI-Resist
* Low and Medium Alloy Gray and Ductile Iron

After an initial SLF assessment and an 8 week Job Shop Lean engagement cycle time for the largest SLF castings (Air Set Floor) was reduced by 19%, floor space was freed up and being better utilized and recommendations to reduce scrap rates were provided but were not completed within the 8 week timeframe of this project. These were being followed up on by the Company.

The Willcor Team developed a unique approach to improving operations for foundries. The Willcor approach varies from traditional tactics that target single cast components and improve performance ‘one casting at a time’. The Team’s methodology took a comprehensive system view and targeted improving foundry operation work processes and product lines.

The project was accomplished in two phases. The first phase was an assessment to tailor the plan to the unique needs of the MCS foundry and ensure an effective use of resources. A ‘menu’ of activities was presented to the MCS management. The MCS selected activities and the Willcor team formed action groups with the foundry to accomplish those activities.

After completion of a process assessment by a foundry expert and process mapping to understand this MCS’ unique operations, brainstorming on constraints and desired improvement areas was used to develop a candidate list of improvement projects. These projects generally addressed reasons for scrap, constraints that limited capacity, and also methods to reduce transportation and handling, both of which had a positive impact on cycle time and projected lead times.

1.3.2 Summary, Results Obtained and Conclusions

1.3.2.1 Job Shop Lean

The objective of this project was to investigate, develop and deploy methods of Jobshoplean (JSLean) manufacturing in a foundry facility that supplies castings to the maritime defense and commercial sectors. Objectives were to look for opportunities to reduce lead time and cycle time of castings by reducing non-value added foundry floor activities and office processes supporting these foundry processes. Additional goals were to improve quality, cost competitiveness, improve mold making (a constraint), reduce floor space requirements, and improve the storage/movement of patterns.

Based on a kick-off site visit and meetings with Team SLF, the following projects were initially planned for:

- **Improve efficiency of Air Set Floor operations and processes:** Air Set Floor (large molds) are the largest part of the operation in dollar sales volume. Typical Air Set molds were taking an average of almost one and a half hours to prepare before a pour could be conducted. The goal was to reduce this cycle time. Additional floor space was also desired in order to increase capacity and flexibility. Reduced cycle time and increased floor space was to be obtained by (i) eliminating unnecessary or rarely used items using and (ii) organizing the upsets and other supplies more efficiently and closer to the technician.
- **Relocate the green sand pile:** Identify alternative locations for the reclaimed green sand pile to reduce material handling times/costs and delays, decrease congestion in the area (as well as safety hazards due to back-and-forth forklift traffic.)
- **Better storage of Patterns in the Pattern room:** Eliminate unnecessary patterns and systematize, through better organization, the layout of the pattern room based on usage priorities of the patterns. The goal was to reduce search and handling time.
- **Core Room:** Organize the core room by adding shelves and promoting visual management by using lean 5S methods with the goal being to reduce search time.
- **Consumables storage room:** Using 5S and red tagging in this storage room to increase available floor space for higher priority items.

The results obtained showed that Job Shop Lean can have a marked effect on a foundry in a relatively short period of time when properly applied. After an 8 week Job Shop Lean engagement cycle time for the largest SLF castings (Air Set Floor) was reduced dramatically, floor space was freed up (at the mold lines, pattern room, core room and storeage room) and better utilized. Positive impacts included;

- Cycle time for the largest SLF castings (Air Set Floor) was reduced by 19%
- Additional foundry floor space of 500 Sq-ft made available due to 5S activities.
- The opportunity to increase throughput by 20% by adding a unskilled support person or “water strider” could generate $176,000/yr in revenue given available sales opportunities.
- The intangible benefits to be gained are improved employee morale from working in a an orderly workspace, greater engagement and ownership of the areas (possibly resulting in reduced damage to molds), visual accounting of WIP/supplies and completed molds.

1.3.2.2 Technical Process Assessment

A two day process assessment was conducted by an expert with extensive experience operating advising foundries with similar operations. After observing operations and analyzing scrap data the following observations and recommendations were made;

- Two of the SLF mold/casting lines had noticeably higher scrap rates than the others.

- In some cases castings were being handled roughly or while they were too hot and being subjected to thermal shock. Training and greater supervision was recommended to ensure castings were not moved until they had cooled appropriately.
- Exothermic hot toppings were not used on a regular basis to ensure proper feeding from risers. It was recommended that SLF use exothermic hot toppings on a regular basis to reduce defects associated with shrinkage.
- Gas porosity problems and observation of moisture/condensation in some molds was observed. It was recommended that additional gas escapte holes be made in molds to reduce gas porosity issues. Mold dryers and other techniques may be needed if these problems persist.

These recommendations are expected to improve quality and reduce scrap rates. They had not been fully implemented as of the end of the project due to the shorter timeframe for the SLF project. These recommendations were being followed up on by the Company as the project was being completed.

2 In Depth Analysis and Discussion

The In Depth Analysis and Discussion of the results of the two MCS units are included as attachments A and B.

Attachment A

Maritime Cast Shop Integrated Improvement Plan

PRL Industries

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Understanding future effects of today's decisions

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Mr. Dan Gallo

EXECUTIVE SUMMARY

The Maritime Cast Shop Integrated Improvement Plan, sponsored by the Defense Logistics Agency's Industrial Base Innovation Fund, resulted in significant increases in productivity, reduction of work-in-progress, and substantially reduced cycle times that will lead to reduced casting lead time at the participating Maritime Cast Shop (MCS).

Key company measures over the most recent six months (June-November 2009) of this project demonstrate the impact of the plant floor improvements described in subsequent sections:

- 20% Improvement in efficiency in Upgrade and Inspection
- 26% Reduction in work in progress (WIP)
- 28% Reduction in the close out report rate through the quarter ended Sep 2009
- 34% Value added capacity increase in Inspection (constraining department) resulting in reduced cycle/lead time
- 4.7% Scrap reduction from the same timeframe of the previous year

The Willcor Team developed a unique approach to improving operations for foundries. The Willcor approach varies from traditional tactics that target single cast components and improve performance 'one casting at a time'. The Team's methodology took a comprehensive system view and targeted improving foundry operation work processes and product lines.

The project was accomplished in two phases. The first phase being an assessment to tailor the plan to the unique needs of the MCS foundry and ensure an effective use of resources. A 'menu' of activities was presented to the MCS management. The MCS selected activities and the Willcor team formed action groups to accomplish those activities. Sites at which MCS improvement activities were conducted included the MCS upgrade facility and the MCS foundry operation.

At the MCS upgrade facility, the Willcor Team conducted projects centered on the principles of Lean Engineering and JobShop Lean. The first significant activity was to perform Lean engineering training. Brainstorming with the MCS on limiting constraints and desired improvement areas lead to a number of projects. These projects generally addressed constraints that limited capacity and also methods to reduce transportation and handling, both of which had a positive impact on cycle time and projected lead times.

At the MCS cast operation, the goal was to provide off-the-shelf cost effective tasks that would lead to improved 1st time casting quality. As efforts progressed, training in Lean Engineering principles was added to the scope of the work and resulted in the conduct of 5S shop organization efforts as well as the establishment of daily stand up meetings between mechanics and supervisors. Projects that successfully went forward included improved facilitation of scrap and revert, use of 3-D CAD drawings, and mold heating. Though not completely implemented at the time of this report, progress was made in the implementation of Manufacturing Resource Planning software, temperature monitoring and weight management at the melt station improvements.

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1 SUMMARY

1.1 INTRODUCTION

Under the auspices of the Maritime Cast Shop Integrated Improvement Plan this project provided significant improvements to a specialized maritime defense and commercial sector foundry.

The Willcor Industrial Base Innovation Fund (IBIF) proposal was a result of observations made while assisting General Dynamics Electric Boat to improve their supply chain which included critical casting suppliers. Shipbuilders periodically experience construction schedule delays with resultant cost increases resulting from castings issues. Casting issues in shipbuilding include the late delivery of components as well as the late discovery of latent quality issues. Costs of shipyard delays are typically vastly out of proportion with the actual cost of the casting itself.

During the conduct of previous efforts, it was noted that casting houses supporting U.S. Navy shipbuilding have several common characteristics:

- The manufacturing effort is typically high mix, low volume
- Radiographic casting upgrade processes and the subsequent defect weld upgrade, review and approval process is a cycle time driver
- The business is frequently small, often under one hundred employees
- Environmental policies discourage the development of new casting businesses or expansion of existing operation, and therefore most of the maritime foundry industrial base has been established for several decades
- The business has not made the investments to incorporate state of the art practices in;
    - Physics based finite element solidification modeling software tools
    - Technical process innovations and improvements
    - Continuous improvement techniques developed specifically to support reducing cycle time and waste in high mix, low volume manufacturing

Based on benchmarking and other related work, Willcor conceived of an approach to improve foundry product lines beyond the traditional tactic of improving "one casting at a time." The proposal included four elements integrated into a program designed to improve the upgrade process and first time cast component quality:

- Job Shop Lean - reduce production lead times on short-run, low volume, castings
- Physics Based Software Tools – off the shelf technology to improve mold design
- Technical Processes Assessment – deploy industry best practice technologies
- Computed Radiography – digital files to replace costly film and improve cycle time

Significant progress was made on these tasks with the exception of Computed Radiography. The delay of approval by NAVSEA for standards for the application of Computed Radiography on nuclear, Level I and SUBSAFE components, the primary products of this foundry, made the execution of this task problematic. (Note: The MCS foundry has decided to buy Computed Radiography equipment for preliminary quality and information shots. The forward leaning thinking of this foundry will place it at the forefront of Computed Radiography use once these standards are approved.)

The MCS decided to partially implement the Physics based solidification modeling capability as originally proposed by BMP. The MCS had questions on the cost benefit equation given the very small production runs and the investment in Computer Aided Drawings (CAD) which have not been made available from the customers. The portion of this task that was completed was highly successful. The MCS hired an engineer who was trained under this task in CAD tools. The CAD capability allowed the MCS to outsource solidification modeling to an outside provider.

The success criteria of this project is the number of recommendations and projects that are "transitioned" for use by the MCS. The Maritime Cast Shop Integrated Improvement Project resulted in the implementation of numerous plant flow changes, concepts and technologies with significant investments made by the MCS, all of which have contributed to significant improvements in the manufacture of cast components and the reduction of schedule and cost risk to submarine and aircraft carrier construction shipyards. A summary is provided as Attachment A.

1.2 Summary, Results Obtained and Conclusions

1.2.1 Job Shop Lean

Typical lead times for maritime sector valve bodies are about 30 weeks. Larger castings such as hatches and hull trunks are typically double this lead time. A cladding process applied to a cast component can have lead times that approach two years. Job Shop Lean (JS Lean) has successfully reduced similar lead times when applied by the DLA R&D Enterprise Team (DLA-J339) and the Logistics R&D Branch (DLA-DSCP) to forges in the aviation and land sectors. The Willcor team successfully applied JS Lean techniques to maritime sector foundries during the course of this work.

The MCS upgrade facility (Upgrade) and foundry (Cast shop) are true job shops; they both contain a number of "monuments" and job-to-job variation demands a high degree of flexibility on the shop floor. The foundry and weld upgrade facility are integral parts of the value stream. Upgrade is integral to the nuclear, Level I and SUBSAFE maritime foundry castings and determines about 65-85% of product lead time.

The primary goal of this task was to reduce the average cycle time for castings that are processed in the upgrade facility. Second tier objectives which supported the primary goal were:

- To reduce the total time spent to complete weld/grind/inspect cycles for emergent repair on the castings
- To improve work-flow and reduce Work in Process (WIP) by improving the storage, control of workstation queues, and improving scheduling and tracking of active orders
- To identify and improve production constraints and bottlenecks
- To increase value-added utilization of resources in the work cells identified as constraints

Attachment A

During early efforts the Inspection Department was identified as a critical constraint which, along with other intra-shop transportation and handling, contributed to a large amount of WIP present on the shop floor.

- To achieve these goals and objectives, specific projects undertaken were: Implementation of a manufacturing cell and associated area layout improvements which reduced casting transportation and handling.
- Implementation of a scheduling system between the constraint department (Inspection) and the non-constraint departments (Grinding, Welding and Radiography.)
- Improvements in the Inspection Department (constraint department) layout, supporting tool access/organization, which improves overall plant throughput.
- Analysis and identification of ways to improve throughput in shipping and receiving which was co-located with inspection.

Initial focus was placed on improving the overall plant constraint, which was inspection capacity. The Team initially found over production at several work centers in the upgrade facility. Inspection did not have the capacity necessary to increase throughput and therefore reduce cycle and lead time. Theory of constraint methods were applied to this bottle-neck and the team achieved a throughput increase of 34% at inspection.

Based on analysis of a sampling of casting patterns, the MCS decided to implement a cell that would co-locate workstations for Grinding and Welding. The capability for grinding or welding technicians to perform self inspection using portable Magnetic Particle Inspection hand held units was also developed. This provides technicians the ability to self-inspect and reduces the number of surface defects found at the final 'buy off' formal inspection. The following benefits are realized with implementation of this cell:
- 26% - 42% reduction (part number dependant) in the total number of part moves throughout the shop and reliance on bridge crane and forklifts whose availability and slow speed of operation contribute to inefficiencies
- 20% - 42% reduction (part number dependant) in the number of intra-shop Grind⇒Inspect⇒Weld⇒Inspect loops

Personnel and resource limitations at the MCS required implementation of cell improvements to be accomplished in phases. Phase 1 is complete and additional phases are in planning.

Key company measures over the most recent six months (June-November 2009) of this project demonstrate the impact of the plant floor improvements described in subsequent sections:
- 20% improvement in efficiency in Upgrade and Inspection
- 26% reduction in work in progress (WIP)
- 28% reduction in the close out report (report shows planned to actual labor element per casting and any problems encountered) hourly rate through the quarter ended Sep 2009

- 34% Capacity increase in the overall constraining department, Inspection
- 4.7% scrap reduction from the same timeframe of the previous year

Theory of Constraints methods were applied which reduced WIP, an indicator of increased throughput through the plant and Inspection constraint. Increasing Inspector’s “value added” inspection time by 34% provided concrete evidence of additional capacity gains in the plant constraint. This improvement reduces cycle time and overall lead times of the castings, a key goal of the project. Improved quality of castings, another goal of the overall project, also contributes to reduced WIP as this causes less work content in Upgrade. Scrap rate trends during this six months show a 4.7% reduction from the same timeframe of the previous year.

Improved productivity measures such as reduced labor hours as a percentage of sales are being observed. This observation demonstrates success in removing non-value added activity in the Upgrade and Inspection processes. Initial casting quality also appears to be improving based on the company’s recent casting close out reports. These reports provide data on work performance against standard or planned hours. In a recent set of about forty close-out reports only one casting exceeded planning estimates.

1.2.1.1 Conclusions

Job Shop Lean has proven to be a flexible and adaptable methodology that is equally successful in the MCS foundry as it was in prior DLA forge applications. The MCS foundry and associated upgrade facility has improved in a number of critical areas as demonstrated by improving company measures which indicate capacity/throughput has been increased, which in turn reduces the lead time of critical maritime castings. JS Lean has proven to be an excellent precursor to other technically focused foundry process improvement methods.

1.2.1.2 Lessons Learned

1.2.1.2.1 Process Mapping

It is recommended that process mapping (and value stream mapping) which identifies areas of waste and improvement opportunity areas precede efforts focused on the foundry technical process. Process mapping helps the technology focused efforts get off to a faster start as the entire process has already been mapped out and viewed from a holistic “system” level. The methods/tools used in JS Lean and quality improvement efforts have many similarities and are often synergistic. Group technology approaches which are a cornerstone of JS Lean are an important starting point in a custom foundry such as this that has a high mix/low volume business or product base. The WILLCOR Team believes that the hands on approach taken with an engineer or engineer intern (with appropriate JS Lean training and ongoing mentoring) working onsite with the company accelerated the pace of adoption of the methods and improvements. Strong involvement and coaching of managers by the company President/CEO is essential to achieving the rapid success MCS has seen to date.

1.2.1.2.2 Customer Driven Hold Points

An ancillary issue observed at the MCS and by the WILLCOR team at many other component manufacturers is the untimely accomplishment of customer required hold points. Customer required hold points are essential elements of the customer’s supply chain quality assurance plan. These hold point requirements should not be diminished but should be better managed.

The untimely accomplishment of customer required hold points cause components to be stored as work in progress until the customer can accomplish the inspection. As with any WIP, cost and lead time is increased and instability in schedules is created.

It is incumbent on the shipbuilding industry to recognize this issue and take steps to mitigate its impact.

1.2.2 Physics Based Solidification and Computer Aided Drawing (CAD) Software Tools

During the Assessment phase, the WILLCOR team worked with the foundry managers and senior trade personnel to develop the information relevant to implement physics based software tools and 3-D modeling capability.

The Willcor Team developed an incremental plan to build aptitudes and skills necessary to deploy 21st Century software .tool implementation. The plan identified and enabled the ability to develop critical knowledge and capabilities essential essential for the successful deployment of commercially available physics based solidification tools. The critical steps identified were:

- Identify MCS personnel with credentials and background suitable to learning and using sophisticated engineering software tools
- Train MCS personnel in the use of 3-D CAD software tools supported by physics based solidification suites
- Put the 3-D CAD software into regular use in the mold engineering processes
- Develop the ability to use the 3-D CAD software as the foundation of the development of Computer Numerically Controlled (CNC) machine code for the manufacture of patterns
- Train the MCS personnel in the use of a commercially available physics based solidification software suite
- Validate the physics based solidification software in the cast shop though the use of test pouring
- Make process changes
    - Bidding and marketing operations request digital renderings of cast components
    - Integrate software tools into the core operations of the cast shop and the marketing operation

After reviewing this task, MCS management decided in March that the costs and resources associated with conducting this task would be large and might not be offset by savings over the typical small quantity production runs. As such, it was decided that the immediate implementation of the physics based software tools was not feasible based on present realities of the cast shop operations. All other elements of this task such as the training in CAD tools were conducted. To support activities in this area, the MCS hired an engineer with appropriate computer bona fides. Key cast shop personnel joined Willcor Subject Matter Experts to form a team to execute activities that would enable the 3-D modeling capability.

1.2.2.1 Results

To familiarize the new-hire engineer with casting operations, the team developed a process map for the cast shop. This dual use document was employed as a training aid as well as an overview of operations for the targeting of process improvements, discussed in the next section.

The new-hire engineer had basic knowledge of the 3-D CAD SOLIDWORKS software package and initiated use of this tool to generate digital renditions of patterns. MCS engineers attended training provide by TRIMECH Solutions, an authorized reseller of the SOLIDWORKS software. The foundry then used the SOLIDWORKS software tool to generate digital renditions of patterns.

Both the MCS marketing personnel and the Willcor SME requested digital renditions of cast components to facilitate the use of 3-D CAD software. Customers were either unable or reluctant to provide digital renditions of components.

The MCS has, on a limited basis, started contracting for solidification studies of their more difficult or problematic castings by a third party source. The third party used the 3-D CAD drawings produced by the MCS and evaluated mold design using physics based solidification software. The MCS use of the third party evaluations has so far produced successful castings on two occasions.

The MCS has also stated they would use the 3-D CAD drawings to explore the use of CNC routines with their suppliers.

The MCS ultimately decided not to conduct this task as originally proposed due to concerns of overloading the staff and questions surrounding the return on a substantial investment given the small production runs of each mold modeled. The task was partially completed and successful in that MCS hired an engineer with basic CAD tool skills that were enhanced through training. This placed MCS in a position to use Physics based tools on their more challenging castings with an a third party provider on an as needed basis and positioned themselves to develop the capability in the future if determined cost effective.

1.2.2.2 Lessons Learned

A methodology or partnership approach needs to be developed that would support making the business case for a foundry to justify purchasing and use of these mature yet expensive tool capabilities. Elements of this methodology would include investments in CAD renderings by the design house (shipyards have not yet provided electronic CAD design in this case), and training an engineer or technician to use the CAD and solidification modeling tools. If, as in this case, a business case can not be established, then outsourcing of part of the work or forming a consortium to share the fixed costs may be the appropriate alternatives.

Shipyards and 1st tier shipyard suppliers need to share digital renderings of components with foundries. For several decades, shipyards and 1st tier suppliers have used software packages such as CATIA for overall ship design. These ship design software packages require digital renditions of valve bodies and other components. Component manufacturers require digital renditions to generate CNC routines. Making these items available to foundries will facilitate the use of 3–D CAD drawings in the foundry environment, minimize the cost of pattern manufacture, and facilitate the use of physics based solidification packages.

1.2.3 Technical Process Assessment

The MCS produces quality castings for markets that accept only the best available cast parts for use in the most critical, nuclear, Level I and SUBSAFE, applications. Observations from visits to the MCS cast operation and upgrade facilities show that high quality products are being manufactured and shipped.

The goal of this operation must be to make defect-free castings; the first time and every time. The careful selection and application of commercially available off-the-shelf technologies and training will improve first time quality of as-cast components and facilitate meeting customer specifications without extensive upgrade activities.

Production of castings with surface and/or internal flaws requires the defects be identified by inspection, ground-out, occasionally weld repaired, and inspected again. Typically, this is an iterative process. Lack of 1st time quality can be responsible for significant amounts of process time and production costs. It is a well established principle that it is not possible to inspect in quality.

In the Melt Shop, all procedures must be written and followed for every casting produced to ensure the consistency of process. Melting alloys requires that chemical compositions are to specifications and, as importantly, furnace operations and practices must be replicated each time a heat is made. Molding and casting procedures must also be adhered to for every part that is cast. To support failure analysis and quality record keeping functions, appropriate data must be recorded and archived.

The MCS cast shop operation produces a wide variety of alloys, including steels, stainless steels and cupronickels, in a wide variety of sizes. This exacerbates process control compared to a foundry that produces the same grade of steel day after day which is cast it into similar sized molds. The changes recommended in this report, especially those that are procedural, are for the purpose of creating processes that can be duplicated irrespective of the alloy being melted and cast. It can not be over emphasized that <u>each</u> alloy has its own metallurgical properties and the procedures used to produce it are specific for that material, and the written instructions for that grade of alloy must be satisfied.

A critical improvement is the frequent and accurate measurement of temperature. Temperature control is important to achieve the desired chemical composition and to consistently produce the technically acceptable castings. Weights of charges, amounts added, the quantity of material in the furnace or AOD vessel are essential because the rates of reaction are dependent on composition, temperature and time.

The following recommendations made were primarily procedural and require a minimum amount of capital expenditure. Adoption of the recommended practices and providing additional training to both managing and operating personnel should produce benefits in product quality and delivery.

- Purchase optical infrared pyrometers. A high temperature range to unit for measurements in the 3000^{o} F range and a low temperature range instrument for measuring temperatures less than 1000^{o} F.
- Evaluate commercially available crane scales for suitable for use in conjunction with ladles containing molten metal. A heat shield is required to protect the electronics in the scales.
- Establish a mold heating station using existing mold heating ovens to pre-heat to approximately 250F molds after closing and prior to setting them in place for casting. After proof of the utility of mold heating, explore other commercial mold heating solutions capable of heating multiple molds to supplement the existing ovens.
- Establish melt shop practices and written procedures that will determine actual weights and chemical analysis of revert. Establish a routine that will consume all scrap and revert at the same rate that it is generated to prevent accumulation and the building of inventory. Utilize the maximum amount of revert material to make up all furnace charges instead of using raw materials, such as punchings, which must be purchased and added. Punchings add new dollars to the melt costs whereas revert has already been purchased and is essentially "free" material in the charge.
- Provide additional training in the metallurgy and physical chemistry of the Induction Melting furnace and the AOD vessel to management and operating personnel. Praxair is a source of this service on the operation of the AOD vessel as well as the reactions that occur in the vessel. Instruction on the theory/practice of the Induction furnace can be taught by a qualified metallurgist
- Observations and recommendations were provided in the following areas:
    - Operation Sheet development
    - Process conformance quality
    - Casting Foundry Floor Observations
    - Finishing Operations Foundry Floor Observations

Personnel and expertise were provided to coordinate recommended changes with the following results

1.2.3.1 Results

Optical Pyrometers – Contact pyrometers were determined not to be a viable option for this application. Two brands of pyrometers were used on a trial basis. Neither brand was successful. Both the accuracy and the precision of instruments came into question. . The MCS used two distinct pyrometer types, the first type measured the intensity of the infrared emission. The accuracy and precision of the intensity style of parameter will be significantly affected by the smoke and particulate associated with a pour and was rejected. The second type of instrument was a ‘two-color’ device that is not affected by smoke and particulate. Operations with the ‘two color’ device still resulted in problems with accuracy and precision.

The cast shop uses a bottom pour ladle for teeming molds. On further study, it was determined that mechanics of the bottom pour requires personnel to continually move around the mold and ladle. Signal interference caused by this personnel movement caused the two-color pyrometer to have accuracy and precision issues. The use of a pyrometer is considered essential for process control and failure analysis efforts and the Willcor Team recognizes that a solution which works for this application is still required.

Scales for in process weight determinations – The MCA cast shop is still actively pursuing this technology. They have experienced issues with the size of the scale and heat shield. The ladle and associated crane that services the Induction Melt Furnace have space limitations that have made the purchase of a scale with appropriate heat shield problematic. The MCS is continuing to pursue solutions for this.

Mold Heaters were installed in late-November on a trial basis. The MCS reported that their first use of these items was successful. In mid-December, the Willcor Team traveled to the Propeller Foundry in Philadelphia Pa where these items were demonstrated. Successful pours using this technology were accomplished in late November and early December.

A one day training course conducted by Praxair experts was accomplished. Attendees included cast shop management team as well as the melt work station personnel.

1.2.3.2 Lessons Learned

The Willcor Team developed an understanding of the special issues surrounding a bottom pour operation. Work needs to be accomplished to develop these ideas into a set of best practices.

Many sources of technical help and advice exist for the foundry industry. Searches of references did not find a comprehensive foundry specific “maturity model” which a foundry could use for self assessment of key process areas or a buyer of foundry products use to benchmark a foundry operation.

1.2.4 Computed (Digital) Radiography (CR)

NAVSEA standards for CR of Nuclear, Level I and SUBSAFE systems were not completed as anticipated for this task. The Team decided not to pursue this task due to lack of necessary customer standards. The MCS has recently procured the Virtual Media Integration CR equipment for “informational quality” shots, as opposed to formal customer buyoff. These capital purchases enable the organization to be well positioned for the future.

2 IN-DEPTH ANALYSIS AND DISCUSSION:

2.1 JOB SHOP LEAN

As discussed above, lengthy lead times are associated with maritime shipyard castings. The longest lead times are associated with nuclear, Level I and SUBSAFE components; the specialty of the MCS. Pressure to compress “span” or build time of submarines in order to reduce the cost has been flowed down to key suppliers such as the MCS. To meet Navy shipyard requirements, the MCS needed an approach to reduce the cycle time associated with key components. This was the case for existing promised deliveries and future commitments for customer driven reduced lead time in a multi-year shipbuilding procurement. JS Lean which had been applied by the DLA R&D Enterprise Team (DLA-J339) and the Logistics R&D Branch (DLA-DSCP) to forges in the aviation and land vehicle sectors was applied as part of the overall solution. Differences in the MCS foundry setting included different Naval Sea Systems Command (NAVSEA) quality and part “sell off” criteria.

The foundry and upgrade facility are housed in different buildings but are integral parts of the same value stream. Upgrade is unique and integral to Level I/SUBSAFE maritime foundry castings and is the predominant factor in product lead time. Primary components of lead time as measured by the customer include:

- Administrative (proposal, quote, purchase order,…)
- Foundry cycle time
- Upgrade cycle time (including in process inspections)
- Final Inspection and Shipping

Because the upgrade component of lead time was larger and appeared to have more opportunities for improvement, most of the JS Lean efforts were focused there. Projects reducing non-value added activity such as improved location (point of use) of tools and mold components were conducted at the foundry but are not included here.

Upgrade cycle time is driven by a number of lower level elements which were discussed with MCS for short term/focused improvement efforts. Since Upgrade cycle time can not be measured until a number of months after the casting is poured, improvements in these areas were considered indicators of progress toward the overall goal of reduced cycle time and casting lead time. These lower level elements included;

- Increasing value-added capacity at the plant constraint operation in inspection area (operator time conducting an inspection vs. in set up)
- Reducing the total time spent to complete multiple weld/grind/inspect cycles for emergent upgrade on castings
- Reducing WIP (work in process) by improving the storage, queue size/location and part flow control, and tracking of active orders

To positively impact these supporting elements of overall lead time, specific projects were decided on with the MCS. Initial focus was on improving the overall plant constraint which was inspection capacity and throughput. There was over production in work centers of the Upgrade facility while inspection did not have the capacity needed. Initial projects included:

- Implementation of an upgrade manufacturing cell which combined weld, grind, and as feasible hand held MT inspection operations. This facility layout and process improvement reduced non-value added transport and handling time.
- Implementation of a scheduling board that was located between the constraint department (Inspection) and the non-constraint departments (Upgrade & Radiography). The intent of this visual communication system was to limit the inspection queue to about one days worth of work thereby limiting interference in inspection. This allows inspection to pull in just the castings they can work on in a given time frame.
- Improving the inspection (constraint department) layout, supporting tool access/organization, and work analysis and process improvements. This targeted increased inspection throughput which in turn would improve overall plant throughput. Improved inspection throughput was measured by “percentage of hands-on inspection time” of inspectors to non-value added set up and other operations.
- Work analysis towards identifying ways to improve throughput in shipping and receiving which was co-located with inspection.

Some of the methods applied during this project included:

- Product Mix Segmentation: Product/Part-Quantity analysis and From-To Charts to understand and reduce transportation associated costs.
- Product Mix Rationalization: Detection of and process-re-engineering to eliminate “misfit” routings, detection and elimination of exception operations in manufacturing routings, part family formation for identification of potential for shared machines.
- Facility Layout: Product-Process Matrix Analysis, design of a cell to produce any clear-cut stable part family, flexible facility layouts that are part-Process Layout and part-Cellular Layout, impact of travel distance on use of Transfer Batch instead of Process Batch, etc.
- Material Handling and Shop floor Control for Inter-Cell Flow Management: Visual communications, locations for inventory buffers, queue management at constraint work centers, etc.
- Cross-training and teaming among machine operators: In this case between welders, grinders and inspection. How well is operator and machine time optimized. Are there other plant floor, machine layouts, cells, or cell derivatives which will improve flow and optimize the operation.
- Finite Capacity Scheduling: In what order and at what times should jobs be released into the job shop? In what order to sequence jobs in queue for processing at constraint work centers? Which processes are the bottleneck/s?

2.1.1 Specific Job Shop Lean Analysis, Improvements and Recommendations

Process Improvements in Inspection Department

Attachment A

At the beginning of the project it was determined that the Inspection department was the constraint limiting capacity and the ability to improve delivery times. Indicators included the number and size of casting queues in front of/in Inspection and also in the management time spent identifying and ensuring the most urgent hot jobs got through inspection on a priority basis. Given that this department was the MCS system constraint, numerous improvement projects were explored and suggested for implementation. Capacity improvement in Inspection was made through a series of improvements in workspace layout, tool accessibility, and unskilled labor support to keep the Inspectors doing inspections and minimizing their time on setup and other non-value added tasks.

These improvements resulted in inspectors increasing the time they actually spend on inspections (as opposed to set-up or other activities) from 33% to 50%, or a 34% Inspection capacity increase. These measures were based on inspector work timesheet records between July and November.

Ultimately the MCS decided a second Magnetic Particle Inspection system was needed to meet new submarine multi-year procurement order delivery requirements. Based on analysis of casting work flow it was determined that in the short-term, the purchase of a second Magnetic Particle Inspection booth located in the Upgrade department where the layout table was located would provide needed capacity in the best location and mitigate the problem of WIP build-up at Inspection. Based on analysis of the "From-To" chart discussed in the "Analysis of Factory Flow Alternatives" section below (Table 3)**,** 56% of the total material flow in the MCS occurs between the rest of the facility and the Inspection department through a narrow portal that requires transfer between various casting transportation and handling systems. Assuming that the current Magnetic Particle Inspection booth remains in the Inspection area, having the new Magnetic Particle Inspection booth located in the Upgrade department would reduce the traffic into the Inspection department from the rest of the facility by 10%-20% which is the direction the MCS has decided to take. Additional analysis and recommendations on how to optimize utility of the new Magnetic Particle system are outlined in the following section and can be applied in either location, to the new or existing system.

Magnetic Particle Inspection and Parallel Operations

A time study was performed on the wet magnetic particle inspection station constraint of the MCS facility. Figure 2.1 shows the steps associated with the Magnetic Particle Inspection process and time taken to perform a typical task in this booth from start-to-finish.

Figure 2-1 Time Spent at a Work Station

The total time the part was in the booth was 1 hour 42 minutes. This means that not only is the booth occupied for 1 hour and 42 minutes, but also the inspector doing the work is occupied doing the tasks listed in the histogram. If the work is divided as shown in Figure 2.2, an unskilled material handler can perform the tasks listed in red, while the inspector (whose skills are needed to perform the tasks in green) would do only those tasks shown in green. If this resource can be shared across two or more work areas in the Inspection department, then the material handler and inspector could work in parallel. As the inspector is finishing up inspecting a part, the material handler can begin setting up the next job the inspector is scheduled to work on. Thereby, the inspector would be occupied for only 60 minutes rather than the 1 hour and 42 minutes (due to his working at a single station). The Cost-Benefit analysis for this new approach can be summarized as: Is hiring an additional material handler and setting up an additional work station adjacent to the Magnetic Particle Inspection booth worth the 42% reduction in cycle time (or increased capacity) at a workstation in a department that is currently the bottleneck for the entire shop?

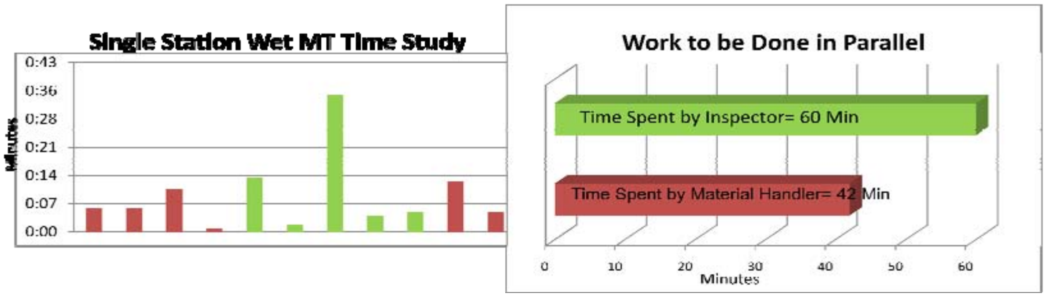

Figure 2-2 Single Station Wet MT Time Study

In order for work to be done in parallel, the layout of the Inspection department must be altered to suit the change in work procedures. This layout change decision should be made in conjunction with other strategic changes in the facility layout, such as opening of the wall that separates the Upgrade and Inspection departments and the implementation of more Grind⇒Weld⇒Inspect cells in the future.
If future ferrous orders support a second Magnetic Particle Inspection booth system it is recommended that this be installed near the Upgrade weld/grind areas, potentially between these and Radiography. Proximity to the weld/grind booths would reduce movement and handling of large castings that require this inspection as discussed in the previous section. Different layouts and casting part flow alternatives can be analyzed and compared in more detail using software tools such as PFAST, STORM and ARENA. Consideration must also be given to what some of these “brick and mortar” changes will have on associated roles, responsibilities, and cross-training of employees.

Based on additional analysis MCS management has considered adding an electric lift pallet truck, a jib crane, and expanding existing cranes in Upgrade and Inspection to minimize wait and handling time. Management should discuss with employees optimal use of these handling devices. Feedback should be obtained on the following sample guidance policy for prioritizing bridge crane and other handling equipment use;

- Bridge crane used for loading/unloading castings in the Grinding, Welding, Inspection booths and
- Bridge crane used for transporting the castings between the Grinding, Welding, Inspection booths.
- Pallet truck or other floor mounted mobile devices for other lineal travel to lower crane usage and associated crane waiting time.

Manufacturing Cell for Improved Material Flow

Figure 2.3 shows the “Spaghetti” diagram for the routing of a single representative casting. Currently, the representative casting must be moved a total of 270 times to complete all the operations listed in its associated work traveler. Due to the size and weight, the only material handling equipment capable of moving these castings are the overhead bridge cranes and forklifts in the Upgrade and Inspection departments.

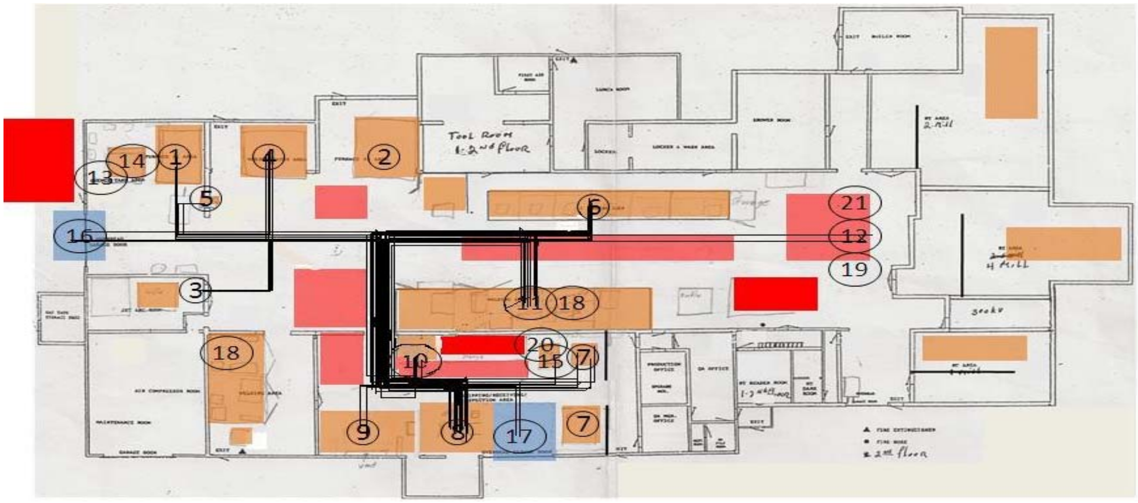

Figure 2-3 Spaghetti Diagram of Operations

Not only does this casting make a total of 270 moves but it must travel 95 times through the narrow 9 ft.-wide opening separating the Upgrade and Inspection departments. Further, 55 times out of the 95 times this casting traveled in an "internal loop" across the building between the Grinding (W/C #6), Welding (W/C #11) and wet Magnetic Particle Inspection (W/C #8) departments, as shown in Figure 2.4.

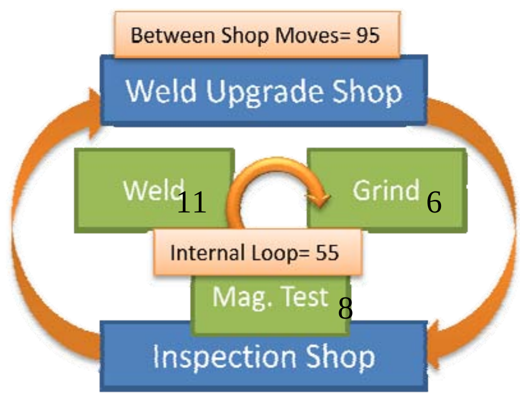

Figure 2-4 Upgrade, Inspection Process Map

Figure 2.5 shows that the Grinding, Welding and Magnetic Particle Inspection operations contribute to 53% of total time spent upgrading the casting. Figure 2.3 shows these work centers are distributed throughout the MCS and separated by large travel distances. These travel distances, in combination with the multiple internal rework loops, result in excessive material handling costs and delays order completion. The "spaghetti" diagrams for four other castings showed similar frequencies of occurrence of the "internal rework loops" and large travel distances. The large inter-work center travel distances not only contribute to an increase in cycle time for order completion, but also complicates order tracking through visual management due to the lack of direct Line Of Sight (LOS) between key work-centers. Furthermore, the build-up of excessive WIP queues in front of work centers increases inventory carrying costs, as well as decreases the efficiency of floor space utilization.

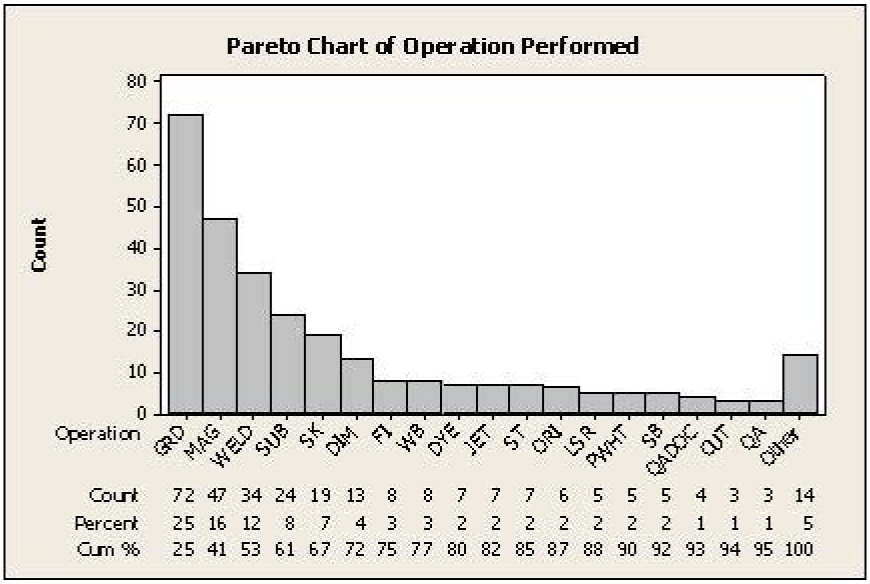

Figure 2-5 Operations Weightings Chart

To combat the issues discussed above, a work cell was implemented that co-locates Grinding, Welding and hand held Magnetic Particle Inspection. The cell co-locates multiple consecutive operations in the routings of many castings into a single work area that can be shared by cross-trained employees who provide all the necessary resources to process that family of castings. By combining operations in one work area, reducing the inter-operation travel distances/handling, and allowing quick feedback between operators on quality-related issues, this cell delivers significant performance benefits. The MCS is investing considerable effort to change the culture of their employees and cross-train them to work in a cellular workspace. Two approaches were examined for setting up the cell:

- Dedicate each side of the cell for welding or grinding:

Each side of the cell can be dedicated to be either a weld area or grind area. For either operation, the layout can be optimized for ease of use. The hand-held Magnetic Particle Inspection unit is portable, so the inspection operation can be done on either side of the cell. The major concern for this approach is that parts still need to be moved from the dedicated grind area to the dedicated weld area and vice-versa. However, the worker/s in either area will not have to move their tools and equipment to the other side of the cell.

This leads to the question: Is it better to move the parts or move the workers? For example, when the grinder finishes Part #1, he will have to wait for the welder to finish Part #2 before Part #1 can be transferred from the grind area to the weld area in the cell. In essence, this would tie up both work areas because the cell is designed with grinding and welding in separate areas. However, the grinder could be working on the next part, Part #3, and put the finished Part #1 in the welders queue.

If the grinder can complete 2 parts before the welder completes 1, the cell will not be balanced. Therefore, this approach will work best if the process times for grinding and welding are relatively equal. Observations were that welding and grinding times varied considerably and could not be counted on to be nearly equal.

- Perform grinding/welding/inspection as needed in same location without disrupting part set-up:

The alternative to Option (A), as described above, was to have two flexible work areas able to support the weld, grind and inspection operations using quick changeover fixtures, redundant, or easily moveable tool setups. The two work areas would be a mirror image of one another with easy access to weld machine, grinding station tools and sharing of the hand-held Magnetic Particle Inspection unit. The part would always stay fixtured on the work table, re-oriented if needed, and have all three operations done on it without removing it from the work table. This would eliminate internal rework loops that the typical part needs as it travels between Welding, Grinding and Inspection departments.

The question this raises is; would it be better to have the cell operators move within the cell and leave the part set up, or fix the location where each cell operator works but move the parts between their locations? A potential downfall of this option B (part stays fixed) approach is that the part will spend more time inside the cell and there will be a critical need to clarify and define the work and other responsibilities of the cross-trained workers in the cell. However, if multiple operations are completed while the casting is set up, it will force parts to be worked further toward completion once the part enters the cell. Since the hand-held Magnetic Particle Inspection may not count as a certified inspection, the part will ultimately have to be moved to the main Inspection area so that the formal inspection can be done in the wet Magnetic Particle Inspection booth.

Either option reduces the number of castings that have to travel large distances when they are processed in the main Inspection department, which “elevates the capacity constraint” in that department, reduces the number of internal work loops and maximizes the flexibility of the work areas. Given that the process times for grinding and welding vary and are not generally equal, option B appeared to be the best suited approach.
The physical creation of a work cell can be a time-consuming and expensive endeavor if the proper personnel are not assigned to the task and sufficient resources are not committed. In order to reduce risk, maximize lessons learned, and limit initial investment required, it was recommended that the cell be completed in phases. Phase 1 of the work cell has been completed. Follow on phases that improve material movement and handling with, for example rollers, are being investigated.

Activities Completed in Phase 1 of work cell development:

- Demolish and clean the area where the work cell will be installed
- Decide proper welding machine capability to install in the work cell.
- Remove wall separating two existing work centers.

- Rework electrical shut-off switches, air lines, gas lines, etc. to comply with OSHA regulations and support the new cell layout.
- New construction to be done in the work cell
- Provide adequate storage and space to support all three operations (Grinding, Welding and Inspection) in the cell.
- Cut 4 ft x 6 ft welding table in half to allow 360 degrees of access.
- Re-weld legs on table.
- Install new weld tables into cell.
- Install a flexible curtain between new work areas.
- Move air lines and drain water from air lines
- Modify and install overhead air ventilation for both work areas
- Install weld machines in both work areas.
- Install grinding equipment in both work areas.
- Install swinging curtain gates in both work areas.
- Install small work status boards in both work areas to facilitate visual communication.
- Install protection for water coolant mix pipe.
- Reconfigure the cell, select and cross-train workers selected to work in the cell
- Bring in welders and grinders to arrange tools and layout the workspace per their desires and standards
- Train the welders and grinders to use the hand-held yoke for Magnetic Particle Inspection.

Activities projected for Phase 2 of work cell development:

Based on the discussions above, the second phase of the work cell implementation could be done in two different ways: (a) Either side of the cell can be specialized to do either welding or grinding, or (b) both sides could be designed to be flexible and perform both processes. The other question to address is how best to move the castings between the two work areas? The installation of a roller system would enable workers to move parts back and forth between the work areas, allowing the worker in each station to remain set up for their specific activity. The rollers themselves could be used as a queue area allowing a first-in first-out (FIFO) flow of work in the job queue. One of the following two alternative layouts are recommended for the rollers:

The rollers could be placed in a T-pattern allowing the workers to move in and out of the

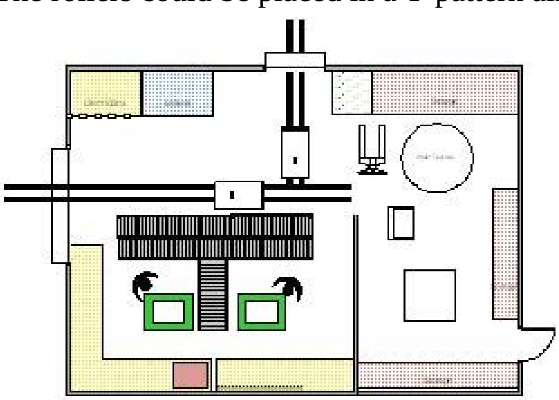

Figure 2-7 Factory Floor 1

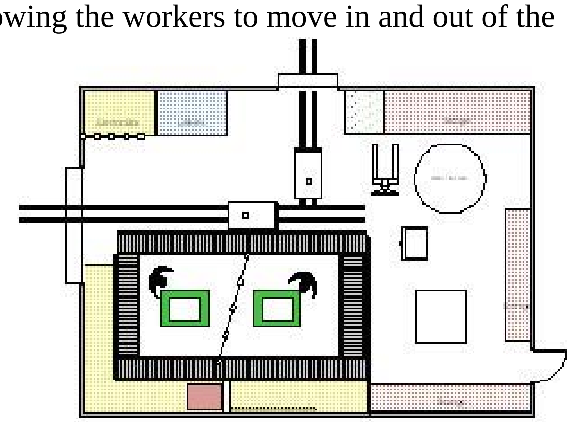

Figure 2-6 Factory Floor 2

Attac

work cell (Figure 2.6) or the rollers could be located around the periphery of the work cell with some form of gate system in the rollers for access (Figure 2.7). In the former design, two lanes in the front of the cell would allow material movement outside of the work area, eliminating the need for a forklift to facilitate movement between each cell area. Ideally, if a worker were cross-trained to complete the welding, grinding and inspection tasks, then the casting could remain set up and would only need to be rotated to have the next operation performed by the same worker.

Activities projected for later phases of work cell development:

After material movement within the cell is optimized, the next step is to integrate the movement of castings into and out of the cell area from the rest of the facility. How can castings best be moved to the Upgrade department and how will castings be moved to the Inspection department without the use of crane and forklift transfers? One option would be to place tracks in the floor to connect the two departments, as shown in Figure 2.6 and Figure 2.7. Factors to consider would be how will the part be transferred from the rollers to a cart or transfer dolly, how many carts would be needed, and do the carts need to allow for movement past each other if there is a change in the order of parts to be worked next in the booth (if moving with bridge crane to the table and multiple carts are within reach of crane this would allow that flexibility.)

Benefits: Combining the grinding, welding, and in-process MT inspection operations in the same area not only remove some of the work load normally routed through the Inspection shop, but it also reduces the total number of moves that the castings make, as well as “internal loops” between the Grinding, Welding and Inspection shops.

Table 1 and Table 2 below summarize analysis of four representative parts for which the work cell yields a 26%-42% reduction in total part moves and a 20%-42% reduction in the number of internal rework loops or cycles between the existing weld, grind and inspection areas.

Table 1 Part Number Moves

QTY	PART #	Total Moves Before Cell	Total Moves After Cell	% Reduction of Total Part Moves
8	5X9HB360A	270	200	26%
8	5X9HB360AFAB	136	101	26%
10	6HMTAM264B	218	153	30%
8	6X15HCDS269E	275	160	42%

Table 2 Part Numbers Before and After Cell

	Before Cell		After Cell	
PART #	Between Shop Loops	Inter shop Loops	Movement In/Out of Cell	Re-Work Loop Reduction
5X9HB360A	95	55	40	42%
5X9HB360AFAB	33	25	10	30%
6HMTAM264B	61	42	12	20%
6X15HCDS269E	77	48	20	26%

Figure 2.8 below shows the more streamlined routing of the part shown originally in the Figure 2.3 "Spaghetti" Diagram when routed through the new cell.

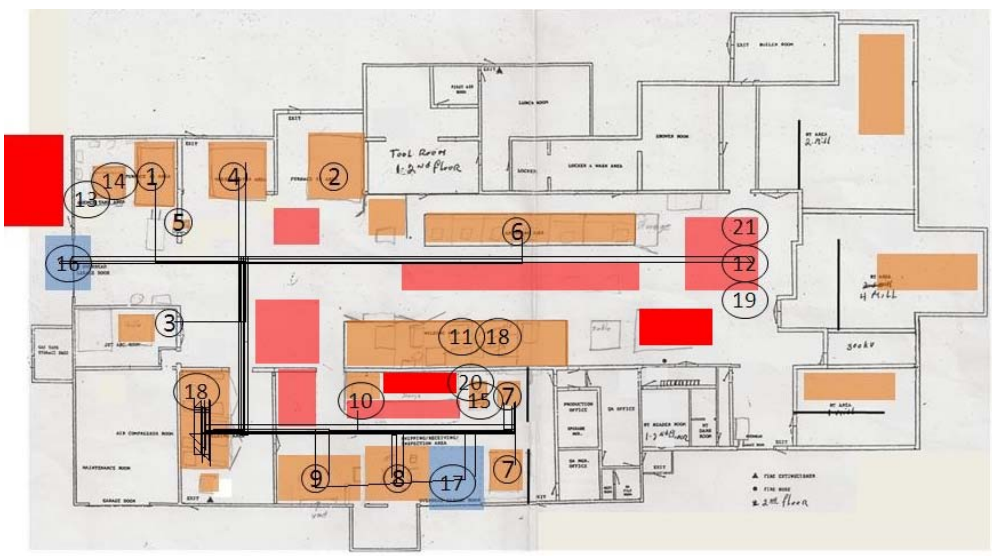

Figure 2-8 Improved Spaghetti Diagram

Not only are casting moves and the number of internal loops or cycles reduced, but also the utilization of the shop's heavy material handling equipment (bridge cranes and forklifts) decreases by "siphoning" some parts into the proposed cell. Figure 2.9 summarizes analysis of the shop's utilization of material handling equipment for the four representative parts before and after cell implementation.

Figure 2-9 Grind Weld Pilot Cell

Considering all four representative parts, the overhead crane in the cell would account for 43%-47% of part moves for those castings, while total part moves for these samples would be reduced between 26 and 42%.

Visible Management Communication System

Perhaps the biggest obstacle in a job shop is the variation in the routings of the castings, as there is rarely a "set path" that any casting travels in order to complete the required work. The problem is more severe with the MCS because the previous operation, or the previous inspection, often dictates the next step in the routing. With more than 50 part moves in a day, it takes an enormous amount of mental capacity, energy and coordination to keep track of each casting's progress over two 8 hour shifts. Tracking of the location and progress toward completion of all active castings can suffer breakdowns in communications between cognizant personnel.

A department Foreman's decision to move a casting or re-arrange the existing production schedule at a particular work station must be communicated by word of mouth to everyone else on the shop floor involved. This can result in excessive part movement, WIP build-up in one or more areas, and blockage of parts flow between departments. To avoid this other job shops have found it essential to create a visual communication system to track parts as they move throughout the shop floor. Visual management systems tailored to the unique needs of a company are a generally accepted lean best practice. A system should be experimented with and designed to relieve the burden of the department

Foreman's daily workload in tracking, locating, or directing technicians casting by casting on which part should be worked next.

Visual Feedback in Weld Upgrade and Inspection Departments:
The Upgrade department in the past had castings of different sizes and shapes stored together in close proximity to one another at various work centers. There are 17 work centers in the Upgrade department and 9 in the Inspection department. Overcrowding is often an issue in both departments since parts wait because their next destination has not been communicated to shop floor personnel, or it has become a lower priority part.

Figure 2-10 Upgrade Facility

Figure 2-11 NDT Inspection AreaSection

Between the line of booths in Welding and the line of booths in Grinding is a rectangular zone in which the majority of the parts are staged. Access to them is with the overhead bridge cranes. If two or more parts are adjacent to each other, how does an operator know which casting is to be worked on next? And, once an operation is complete, where should the casting be located to in order to be ready at the next work center? How does everyone in the shop know where that part is going next? Currently, all communication is through direct contact between the department Foreman and his workers. The foreman makes lists of which parts are to be worked on next and verbally communicates this to the workers. If the Foreman is in a meeting or busy with something else, the worker must either leave his work station to contact the Foreman, or wait for the Foreman to return. These limitations point to the need to create a more effective visual communication process based on work standards relating to part movements, or alternatively, to install a computerized scheduling system.

Recommendations: To effectively communicate the flow of castings throughout the shop, 4 ft x 6 ft magnetic boards have been installed at key locations (Figure 2.12). In addition, a smaller magnetic board has been placed outside each work center. Magnets are assigned to each in process part. Each magnet carries a Part Number, Serial Number, Customer and Description and is used to coordinate and monitor the movement of its casting with those of other castings that are active throughout the shop. The entire process is shown in Figure 2.13 and is described below.

Figure 2-12 Installation of Magnetic Boards

Master Schedule: The Master Schedule will dictate which parts are to be worked as sorted by due date. In the future, use of a Finite Capacity Scheduler would help to modify this EDD (Earliest Due Date) sequence if “drop-in” orders or “Hot List” orders need to be inserted into the schedule based on new business conditions. Once the appropriate castings are scheduled to be released into the shop and travelers are created for each order, magnet labels are created and inserted into each traveler. The process for creating the magnetic tag for each order is documented in Figure 2.13.

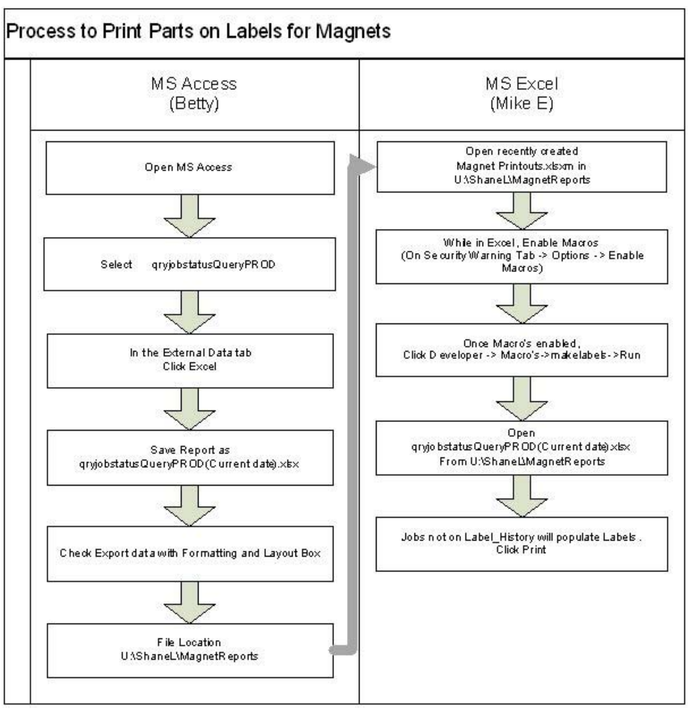

Figure 2-13 Process Flow

Release of Work to the Shop Floor: Work is not to be released into the shop until there is adequate room in the queues. As shown in Figure 2.14 (shown as large triangles), it has been proposed that WIP be allowed to be retained in only three queues: (1) In the Upgrade department in the zone that separates the Grinding and Welding booths, (2) In front of the scheduling board located between the Upgrade and Inspection departments near the opening between the two departments and (3) In the Inspection department. Due to its location, Queue #2 will also feed castings into and out of the pilot cell.

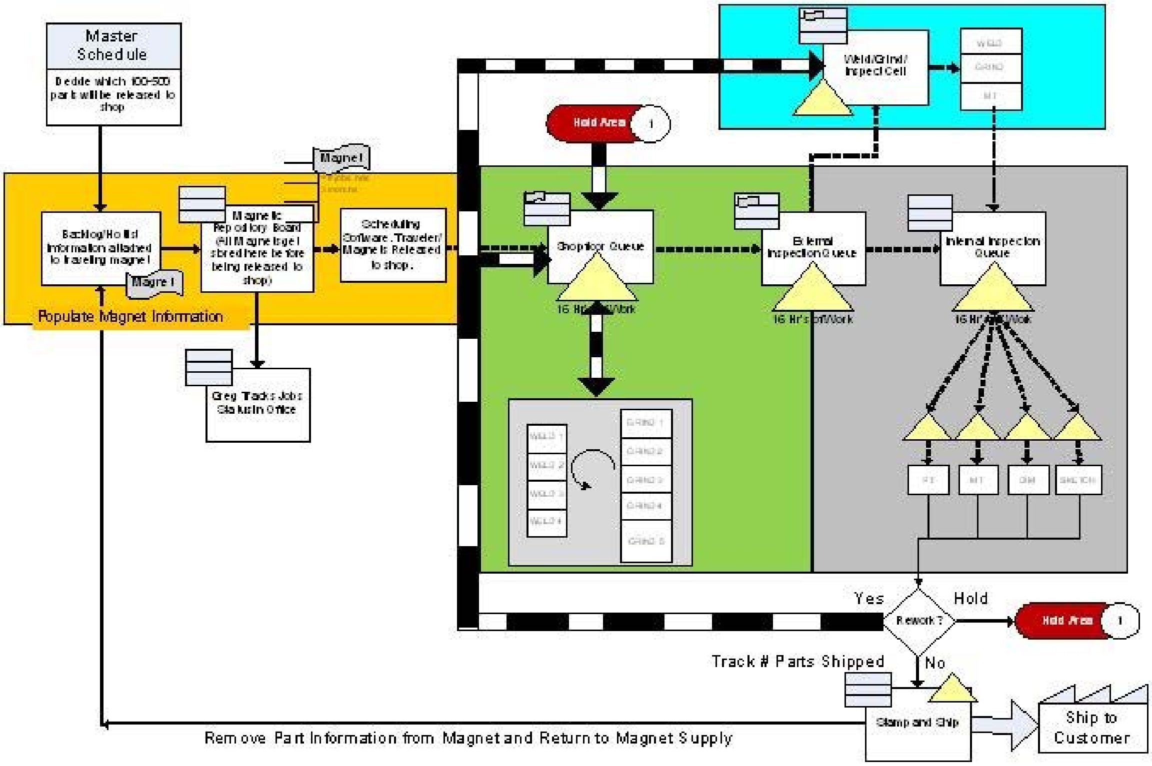

Figure 2-14 Casting/Magnet Visual Tracking System

Queue Area 1: Castings coming from the Inspection department, castings coming out of the hold area in the yard, castings being released into the shop and castings coming from any of the 17 work stations in the Weld Upgrade area should all be tracked using this board. As castings are removed from this area and space becomes available in this queue, new work should be released. Castings from this area will be routed to Queue Area 2 for inspection operations or into the pilot work cell.

Queue Area 2: This area controls the flow between the Upgrade and the Inspection departments. Initially, it is suggested that this queue area be allowed to carry approximately 8-16 hours of Inspection work at any time to serve as the buffer between the two departments. This buffer size will need to be experimented with. The castings queued up in this buffer area could require any combination of inspection work on the VT, MT and PT workstations of the Inspection department. This buffer will include castings needing dimensional analysis, magnetic particle inspection and dye penetrant inspection. As castings are removed from this area and space becomes available in this queue, new work would be pulled from Queue Area 1.

Queue Area 3: This area is specific to operations being performed in the Inspection department. The scheduling board should have areas that would carry the magnets for each of the 4 major types of inspection work done in the department;

Dimensional/Visual, Magnetic Particle, Dye Penetrant and Sketch. An alternative layout of the castings being staged for work in this area has been proposed to help with work queue management. Figure 2.15 shows (as shaded blocks) this potential staging layout of the Inspection area.

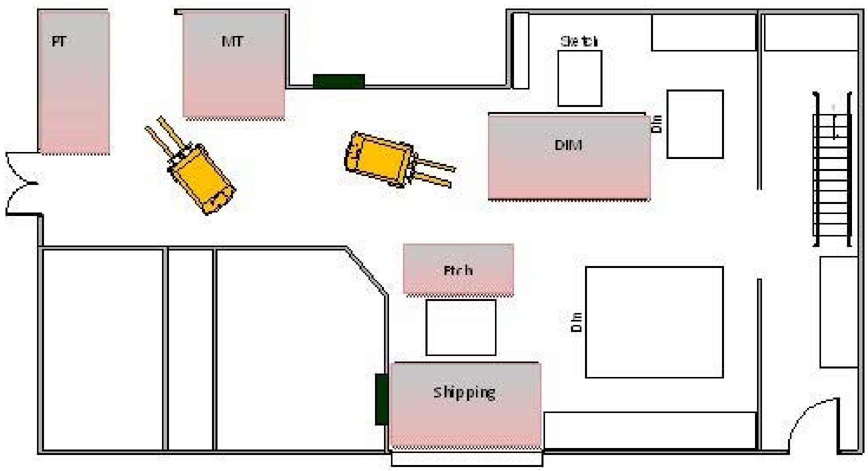

Figure 2-15Inspection Floor Buffer Arrangement

Shipping Area: A board placed in the Shipping area would be used to track daily and weekly shipments of castings. Delivery performance should be tracked to show the overall performance of the shop. Every week the board should be cleaned and magnets returned to the Quality Assurance department for future re-use. It is recommended that delivery performance be recorded in a log so that cumulative performance to promised delivery date can be assessed on a regular basis by management. Alternatively, Profit Key data could be updated after the shipping invoice is printed to retain actual delivery dates and a record of performance for monitoring trends.

The goal of the scheduling boards and magnetic job tags is to visually communicate the movement of parts throughout the shop and provide visual feedback as to the part's progress at any given time. They also serve as a short-term "stop gap" measure until the scheduler system is brought online. The Master Schedule will control the scheduling boards and the boards will tell the operators which parts they should work in order to meet required delivery dates. The department managers will re-sequence parts based on experience, priority changes, or current work flow requirements in the shop.

Another use for the boards is to communicate queue control logic and introduce discipline in how space is used to store parts and in material handling associated with moving parts in a queue. The parts in the designated queue areas should be matched to the magnets on the scheduling boards. Those parts in the queue area for which magnets do not show on the boards should alert management that further training for the employees, or more process discipline, is needed. If the boards are not easy to use an alternative approach for coordination and production control should be explored that meets the goals discussed.

In the short term, it is important to teach employees how to determine sequencing and scheduling priorities, and how that will influence the "pulling" of new castings into space left open after castings were pulled out of those queues by downstream operations. It is anticipated there will be a need to expand or contract the area and shape of each queue, since the castings have significantly different shapes and weights. This will have to be addressed in the future layout of the facility, including the installation of material handling approaches that would allow for the castings to be more easily moved as order priorities change, castings are shipped, and new castings arrive.

Additional Considerations for Coordination/Production Control:
Possible improvements to the visual communication system include use of a barcode or radio frequency identification (RFID) tag system to track part movement and progress. By providing a start and end time for each transfer/move made by any part, employees could track in real-time the progress of a part. Tracking the deviation of actual time spent working on a part and estimated time spent working on a part will allow the Sales department to more accurately predict and quote lead times.

With the ProfitKey system is fully operational, a barcode system with a scanning gun could be used. PorfitKey with the bar code function has the capability to tell you instantly where the part is and/or the last time it was worked on. This can be checked at any time on ProfitKey by going into the program. The ProfitKey system does not at this time support a remote bar code scanner and these must be attached to a computer at the work station. Maintaining and operating a computer in a high dust environment would need some consideration such as a protective enclosure with vent screens, or extended cables with location of the computer on the other side of a wall in the inspection area or other such area. Such electronic tracking of the movement of parts through the queues will progressively reduce reliance on the manual visual communication system. It would also eliminate labor time associated with employees maintaining time sheets once the part has been completed at the workstation. Training in production planning and control should be provided to personnel who will be responsible for working with and executing the schedules produced by ProfitKey.

The MCS plan is to update to the latest version of ProfitKey, put in parameters, tie serial numbers to unique lot numbers, modify the travelers (which ProfitKey prints out), improve the scheduling detail on quotes, and then conduct a dry run of several complex jobs as part of a transition process. This will be followed by possible modifications in the ProfiKey program, as needed and adding the bar code capability.

MCS management can consider contacting Mr. George Rogers (Ph: 716-897-2288) for feedback on their lessons learned in a similar transition of their ERP system, E2 (from ShopTech Corporation), to track jobs in their job shop operation (Kehr-Buffalo Wire Frame Co. Inc, www.kbwf.net)

Benefits: The creation of a visual management system will increase LOSE (Line Of Sight Efficiency) throughout the facility by about 50%. This will reduce the time spent looking for & tracking castings and also the amount of time personally directing technicians on which castings to be worked next. This will allow managers to reallocate time from the tactical to more strategic type of work including training and mentoring. Sales employees will more quickly be able to report on the status of orders when customers call in and employees will be able to determine where a casting is by going to the boards vs. walking the floors.

Visual Management in the Parking Lot
Upon entering the MCS facility, one observes rows of castings sitting outside the Weld Upgrade shop (Figure 2.16). Some castings have been exposed to the elements since rust is visible on them, others have shiny machined surfaces indicting they have recently returned from the machine shop. Other castings may be cooling down after having been removed from the Heat Treatment furnace and others have just arrived after having been poured at the foundry and still have casting gates attached. Some of the castings are stacked in front of each other, preventing access and leading to wasted labor when the casting in front has to be moved in order to access the casting behind it. Some questions that arise when one observes this storage of castings (or any physical inventory for that matter):

- How does someone inside the shop know what is out in the yard without physically walking out and taking inventory?
- Which parts have been brought in from the foundry to be released into the shop?
- Which parts are left outside to cool after being removed from the Heat Treatment furnace?
- Which parts are on-hold waiting for government disposition?
- Which parts are to be scrapped?

Figure 2-16 Parking Lot

Recommendation: It is recommended that a system be developed to organize this storage and staging area. This could be started by writing a brief statement as to why each casting is being stored in the area. Every few weeks repeat these steps in order to capture a good mix of castings that come through. An Affinity Diagram can be used to group similar reasons together. Once the needs for this area have been established, create designated areas for each grouping per the Affinity Diagram. The areas can be as simple as spray painted boxes on the lot establishing boundaries or as complex as an outdoor vertical shelving system. The design of this storage area should allow access to all parts from all sides. To protect machined castings or castings that have had previous work done on them, the castings could be wrapped in plastic or put inside environment-protection boxes, for example a crate wrapped in plastic. Once the areas have been established, they should be clearly marked in order to visually communicate the availability of free space, the on-hand inventory of castings by type currently in the area and how long any casting has been held in the area. This information can be tracked on a board inside the shop to prevent the “piling up” of excessive WIP of these castings in this area.

Benefits: By providing immediate visual feedback, this will reduce the need for material

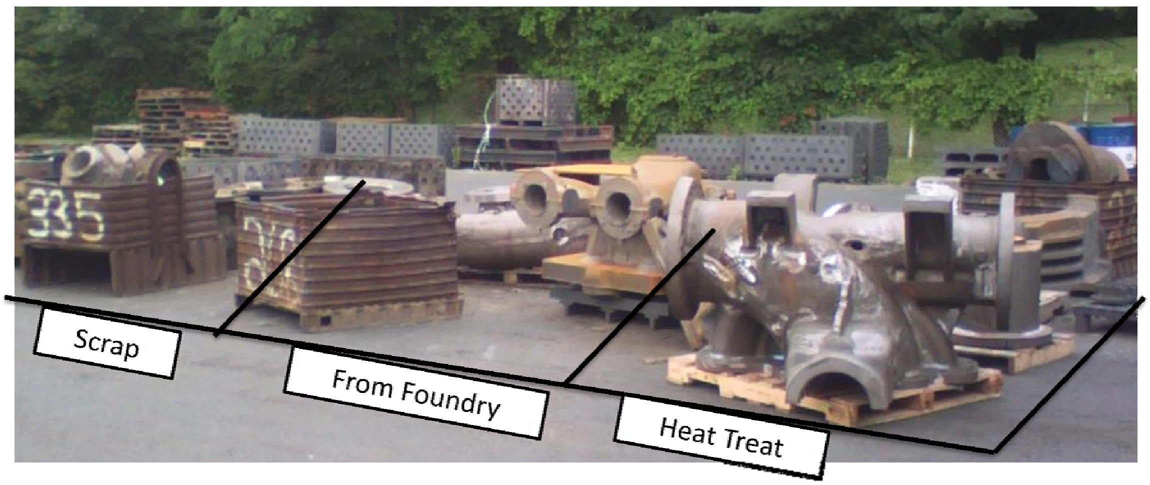

Figure 2-17 Parking Lot Staging

handlers, and department Foremen to expend time looking for parts. This will not only improve the organization of the area, but also support documentation as to how the shop is running at the current time. For example is there too much work being put on hold? Such a design will reduce the tendency for people to dump parts since this can result in a LIFO (Last In First Out) withdrawal process and potential for more difficult access to castings staged in the area at an earlier date. Figure 2.17 presents a possible solution for the design of the outside storage area without showing access lanes between the sections which should be included.

Analysis of Factory Flow Alternatives
This section provides additional analysis of MCS plant flow not addressed in the sections above and provides some answers to questions relating to the MCS facility layout.

Wall Restriction Between Upgrade and Inspection: As discussed in some of the sections above the MCS has a single nine foot opening through which all Upgrade work has to pass to get to the Inspection area. This raised the question of what improvements could be made for casting flow between the Upgrade and Inspection departments.

Table 3 below is the "Q" type "From-To" Chart that was generated by a Job Shop Lean tool called PFAST using the routings of representative sample castings. Table 4 is a cross reference of the work center numbering system used in Table 3 and subsequent tables. Table 3 shows the volume of traffic between every pair of work-centers in the facility. The two squares outlined in red represent the material flows between work-centers in the Inspection department and other work-centers in the rest of the shop. The sum of all flows contained in the two red squares is 56.27% of the total flows from the 250 parts captured in the sample.

All these flows go through the single nine foot wide opening in the wall that separates the two departments. Clearly, that opening is a "pinch point." If the wall can not be removed then other options should be considered to a second opening of some type (possibly where a prior opening had been bricked up) to connect the two departments.

$$\frac{Weld\ Upgrade\ \leftrightarrow\ Inspection}{Total\ Traffic\ in\ Entire\ Facility} = \frac{1477}{2625} = 56.27\%$$

Table 3 Upgrade to Inspection Flow Analysis

		TO																				
		Weld Upgrade Shop														Inspection						
From		21	20	22	6	11	12	1	4	3	2	5	13	19	18	9	7	10	8	17	15	16
Weld Upgrade Shop	21				5			1										1			1	
	20	1					1	3	2								2			7		
	22		1		16	2	3	1	1			1				8	10	4	5			2
	6	3	1	8		32	20	6	23	14		4	2	8		92	106	52	211	9	1	
	11			7	144		3	1	2			1	4			12	21	8	26	5	3	2
	12		1	2	17	3		7	1	3	2	7	1			5	11	2	4	2	3	
	1				4	2			28	9	16	5					2		9	1	1	4
	4		2	1	14		6	2		5		2				6	12	2	29	2	1	
	3				63	1	5		8				1			1	1	1	3		1	
	2			1	3		1	1	3	23						1		1	2			
	5			1	10	1	2			1	1					9	8		3		5	
	13				4										1	2			4	3		
	19				3											2	1			2	1	
	18																		1			
Inspection	9			1	75	12	1	2	1	3		2					22	60	1	5	5	1
	7		5	15	44	11	22	27	5	3	3	11				25		28	23	18	29	2
	8	2	6	4	138	18	1	5	6	12	3	3	6			4	41	73		6	7	2
	10			6	31	157	1	1			1	1				15	12		6	2		2
	17				3			2		1	1					4	1		2			49
	15	1			1	1			1			1		1		1	4	1	2	49		1
	16	1		8	19		6	21	3	12	10	3				11	22	2	6	6	3	

Table 4 Work center Location Codes For Table 3 and Subsequent Tables

Work Center No	Description
1	Normalization (heat treat) & PWHT
2	Smaller Heat Treat
3	Jet Arc
4	Wheelabrator
5	Sandblast
6	Grind
7	Dimensional Inspection
8	Magnetic Particle Inspection
9	Dye Penetrant Inspection
10	Sketch
11	Weld
12	Radiographic Test/X-Ray 4 mil
13	Local Stress Relief
14	Quench
15	Shipping Table
16	Receiving Area
17	Shipping Area
18	Weld with Jib
19	Radiographic Test/X-Ray 2 mil
20	Layout Table
21	Radiographic Test/X-Ray 1 mil
22	Subcontract (usually Brenner Machine)

Considerations in location of the existing and additional new Magnetic Particle Inspection systems:

Table 5 shows the original “From-To” of Table 3 modified to show the new shop traffic flows when Magnetic Particle Inspection (MPI) (W/C #8) is moved out of the Inspection department (possibly placed adjacent to the new MPI booth that will be located where the Layout Table is situated in the Upgrade department). Now there is roughly 20% (56.27% - 37.18%) less traffic passing through the nine foot wide “pinch point” in the wall that separates Weld Upgrade and Inspection (assuming that a second opening is not created at the other end of the Inspection department). So, on the surface, it would appear that the decision to locate both MT booths in Upgrade is beneficial. But**,** if the two MPI booths are split between Upgrade and Inspection, then the reduction in inter-department traffic would be halved i.e. 0.5*(56.27-37.18) (assuming equal utilization of each MT booth.)

Table 5 Improvement of Casting Flow

			Weld Upgrade Shop															Inspection					
			21	20	22	6	11	12	1	4	3	2	5	13	19	18	8	9	7	10	17	15	16
From	Weld Upgrade Shop	21				5			1											1		1	
		20	1					1	3	2									2		7		
		22		1		16	2	3	1	1			1				5	8	10	4			2
		6	3	1	8		32	20	6	23	14		4	2	8		211	92	106	52	9	1	
		11			7	144		3	1	2			1	4			26	12	21	8	5	3	2
		12		1	2	17	3		7	1	3	2	7	1			4	5	11	2	2	3	
		1				4	2			28	9	16	5				9		2		1	1	4
		4		2	1	14		6	2		5		2				29	6	12	2	2	1	
		3				63	1	5		8				1			3	1	1	1		1	
		2			1	3		1	1	3	23						2	1		1			
		5			1	10	1	2			1	1					3	9	8			5	
		13				4										1	4	2			3		
		19				3												2	1		2	1	
		18															1						
		8	2	6	4	138	18	1	5	6	12	3	3	6				4	41	73	6	7	2
	Inspection	9			1	75	12	1	2	1	3		2				1		22	60	5	5	1
		7		5	15	44	11	22	27	5	3	3	11				23	25		28	18	29	2
		10			6	31	157	1	1			1	1				6	15	12		2		2
		17				3			2		1	1					2	4	1				49
		15	1			1	1			1			1		1		2	1	4	1	49		1
		16	1		8	19		6	21	3	12	10	3				6	11	22	2	6	3	

$$\frac{Weld\ Upgrade\ \leftrightarrow\ Inspection}{Total\ Traffic\ in\ Entire\ Facility} = \frac{976}{2625} = 37.18\%$$

Consideration also has to be given to the potential “cons” of a decision to locate the new MPI booth in the Upgrade department:

- Is space available in Upgrade to accommodate both booths next to each other?
- Is it economical to re-locate the existing MPI booth in the Upgrade department?
- Will the noise, dust, etc. in the Upgrade department compromise the performance of the MPI equipment and operators?
- Will it be necessary to also relocate VT equipment and personnel from the Inspection department into Upgrade?
- How will this impact material handling due to additional usage of bridge crane and forklifts for the new MPI booths in Upgrade?

Considerations in location of the shipping and receiving areas. Should the shipping and receiving departments be combined:

Using the same sample of castings as above, Table 6 below shows that 19.16% of the total traffic involving all pairs of work-centers in the facility occurs with the Shipping and/or Receiving departments. However, when Shipping and Receiving are considered in isolation, they have almost equal interaction (11.62% and 7.54%, respectively) with the rest of the facility. Therefore, from a “material flow” perspective, there is no justification for grouping these two traditionally distinct functions together. However, for reasons such as labor force utilization, cost of expanding the facility, duplication of assets, etc. there may be merit in merging these two departments.

Table 6 Shipping and Receiving Flow

		TO																				
		Weld Upgrade Shop														Inspection						
From		21	20	22	6	11	12	1	4	3	2	5	13	19	18	9	7	10	8	17	15	16
Weld Upgrade Shop	21				5			1										1			1	
	20	1					1	3	2								2			7		
	22		1		16	2	3	1	1			1				8	10	4	5			2
	6	3	1	8		32	20	6	23	14		4	2	8		92	106	52	211	9	1	
	11			7	144		3	1	2			1	4			12	21	8	26	5	3	2
	12		1	2	17	3		7	1	3	2	7	1			5	11	2	4	2	3	
	1				4	2			28	9	16	5					2		9	1	1	4
	4		2	1	14		6	2		5		2				6	12	2	29	2	1	
	3				63	1	5		8				1			1	1	1	3		1	
	2			1	3		1	1	3	23						1		1	2			
	5			1	10	1	2			1	1					9	8		3		5	
	13				4										1	2			4	3		
	19				3											2	1			2	1	
	18																		1			
Inspection	9			1	75	12	1	2	1	3		2					22	60	1	5	5	1
	7		5	15	44	11	22	27	5	3	3	11				25		28	23	18	29	2
	8	2	6	4	138	18	1	5	6	12	3	3	6			4	41	73		6	7	2
	10			6	31	157	1	1			1	1				15	12		6	2		2
	17				3			2		1	1					4	1		2			49
	15	1			1	1			1			1		1		1	4	1	2	49		1
	16	1		8	19		6	21	3	12	10	3				11	22	2	6	6	3	

$$\frac{(Shipping + \ Receiving) \ \leftrightarrow \ Entire\ Facility}{Total\ Traffic\ in\ Entire\ Facility} = \frac{503}{2625} = 19.16\ \%$$

$$\frac{Shipping \ \leftrightarrow \ Entire\ Facility}{Total\ Traffic\ in\ Entire\ Facility} = \frac{305}{2625} = 11.62\ \%$$

$$\frac{Receiving \ \leftrightarrow \ Entire\ Facility}{Total\ Traffic\ in\ Entire\ Facility} = \frac{198}{2625} = 7.54\ \%$$

Should the Shipping or Receiving departments be co-located with the Inspection department: With reference to Table 7 below, within the Inspection department, the shipping and receiving departments together account for 63.47% of the total casting flow. However, shipping has 25% more interaction with the rest of the Inspection department than does receiving. In view of this it makes sense to keep shipping adjacent to inspection. Discussions to build an extension from the current shipping garage door make sense in order to separate and better organize the flow of parts through inspection and shipping areas. Further analysis is recommended to find out:

- What is common/different in the work content, processes, skill requirements, equipment, quality standards, etc. for the two departments and
- How do they interact with the Inspection department?

Table 7 Flow within Inspection, Shipping and Receiving

			TO																				
			Weld Upgrade Shop														Inspection						
			21	20	22	6	11	12	1	4	3	2	5	13	19	18	9	7	10	8	17	15	16
From	Weld Upgrade Shop	21				5			1										1			1	
		20	1					1	3	2								2			7		
		22		1		16	2	3	1	1			1				8	10	4	5			2
		6	3	1	8		32	20	6	23	14		4	2	8		92	106	52	211	9	1	
		11			7	144		3	1	2			1	4			12	21	8	26	5	3	2
		12		1	2	17	3		7	1	3	2	7	1			5	11	2	4	2	3	
		1				4	2			28	9	16	5					2		9	1	1	4
		4		2	1	14		6	2		5		2				6	12	2	29	2	1	
		3				63	1	5		8				1			1	1	1	3		1	
		2			1	3		1	1	3	23						1		1	2			
		5			1	10	1	2			1	1					9	8		3		5	
		13				4										1	2			4	3		
		19				3											2	1			2	1	
		18																		1			
	Inspection	9			1	75	12	1	2	1	3		2					22	60	1	5	5	1
		7		5	15	44	11	22	27	5	3	3	11				25		28	23	18	29	2
		8	2	6	4	138	18	1	5	6	12	3	3	6			4	41	73		6	7	2
		10			6	31	157	1	1			1	1				15	12		6	2		2
		17				3			2		1	1					4	1		2			49
		15	1			1	1			1			1		1		1	4	1	2	49		1
		16	1		8	19		6	21	3	12	10	3				11	22	2	6	6	3	

$$\frac{(Shipping + Receiving) \leftrightarrow Rest\ of\ Inspection}{Total\ Traffic\ within\ Inspection} = \frac{351}{533} = 63.47\ \%$$

$$\frac{Receiving\ \leftrightarrow\ Rest\ of\ Inspection}{Total\ Traffic\ within\ Inspection} = \frac{107}{533} = 19.16\ \%$$

$$\frac{Shipping\ \leftrightarrow Rest\ of\ Inspection}{Total\ Traffic\ within\ Inspection} = \frac{244}{533} = 44.12\ \%$$

Is there a benefit to installing more Grind⇒Inspect⇒Weld⇒Inspect “partial” manufacturing cells:

The answer is yes based on the reduction in transportation and cycles (loops) between the Upgrade and Inspection departments for ferrous parts that can use the hand held MT inspection. For non-ferrous parts a similar analysis of the upgrade and inspection process is needed to determine if efficiency can be gained by combining some of the inspection elements into a partial cell. Alternatively, the location of non-ferrous upgrade work could be changed such that they were in closer proximity to the appropriate inspection station.

Periodic review of non-value added time with the intent of further reducing it throughout the manufacturing process is recommended. The best justification may have been provided by the case studies discussed in the article emailed to the MCS management team: *Wetzel, S. & Gibbs, S. (April 2009). 8 Answers To Your Lean Questions. Modern Casting, Pages 19-21.* Unfortunately, judging by the Product-Process Matrix that was generated by the Job Shop Lean toolset (Table 8 below), clear-cut part families are not obvious; still, approximate groups of parts that use similar combinations of work-centers have been highlighted using different colors. The primary reason for this is that, despite the existence of many booths in both departments, in the current routings provided Grinding is a single work center (W/C #6) and Welding is a single work center (W/C #11). But, we know that almost all the castings go through a Grind⇒Inspect⇒Weld⇒Inspect sequence multiple times which, therefore, is a logical basis for creating several “partial cells” (aka modules). Also, the Group Technology (GT) literature contains enough evidence that castings can be segregated into families based on for example size, shape complexity, material, etc. It is recommended that MCS management support a detailed Group Technology analysis to refine the current routings for the same sample (or maybe a larger sample) of castings that were used to generate this report.

Table 8 Product, Process Matrix

	16	5	9	12	10	11	6	7	3	8	1	4	2	22	13	17
15714N18	1				1	1	1	1	1	1	1	1	1	1		1
17082N18	1	1			1	1	1	1	1	1	1	1	1	1		1
WD7249565-0021	1			1	1	1	1	1	1	1	1	1	1	1		1
WD7249565-0020	1			1	1	1	1	1	1	1	1	1	1	1		1
WD7249565-0019	1			1	1	1	1	1	1	1	1	1	1	1		1
WD7249565-0008	1			1	1	1	1	1	1	1	1	1	1	1		1
WD7249080-0011	1			1	1	1	1	1	1	1	1	1	1	1		1
6509E61-001A	1			1	1	1	1	1	1	1	1	1	1	1		1
6509E65-003	1		1	1	1	1	1	1	1	1	1	1	1	1		1
6509E65-002	1		1	1	1	1	1	1	1	1	1	1	1	1		1
6509E61-001B	1		1	1	1	1	1	1	1	1	1	1	1	1		1
6D70394H01	1	1		1	1	1	1	1	1	1	1		1	1		1
6X15HCDS1EHYD	1	1			1	1	1	1	1	1			1	1	1	1
6X13BSXFAB/FM	1		1	1	1	1	1	1						1		
50643-00CN3	1	1	1		1	1	1	1	1				1	1		1
342568M	1	1	1	1	1	1	1	1	1					1		1
667723M	1	1	1	1	1	1	1	1	1					1		1
4X9H3A15	1		1	1	1	1	1	1	1		1	1	1	1		1
CC02677	1		1	1		1	1	1	1		1	1	1	1		1
14002N18RM	1		1	1	1	1	1							1		
DO010242BNUCRI	1		1											1		1
16430-00WCB	1		1	1	1	1	1	1	1	1	1		1			1
1-3f-5a	1			1	1		1	1	1	1	1	1	1			1
6X15HCX366A	1				1	1	1	1	1	1	1	1				1
NP3195	1			1	1	1	1	1	1	1	1	1				1
2357-5-4MOD	1			1	1	1	1	1	1	1	1	1	1			1
CP10011009P	1				1	1	1	1	1	1	1	1	1			1
50638-00WCB	1				1	1	1	1	1	1	1	1	1			1
50157-OOWCB	1				1	1	1	1	1	1	1	1	1			1
12487-04WCB	1				1	1	1	1	1	1	1	1	1			1
4-3F-5A01024	1				1	1	1	1	1	1	1	1	1			1
1-6C-1A01024	1			1	1	1	1	1	1	1	1	1	1			1
5X9HB360A	1	1	1	1	1	1	1	1	1	1	1	1			1	1
6X15HCDS1E	1	1		1	1	1	1	1	1	1	1	1			1	1
6X15HCDS269E	1	1			1	1	1	1	1	1	1	1			1	1
6HMTAM264B	1			1	1	1	1	1	1	1	1	1			1	1
5X9HB360AFAB	1	1		1	1	1	1	1	1	1	1					1
5X9HB360ASHELL	1							1		1						1

WP1040(1D & 1B)			1		1	1	1	1								1
WP1040(1A)	1		1		1	1	1	1								1
WP1040	1		1	1	1	1	1	1								1
WP1040 (1B & 1C	1		1	1	1	1	1	1								1
WP1040 (1E(2) &	1		1	1	1	1	1	1								1
WP1040(1C & 1E(	1		1	1	1	1	1	1								1
WP1040-1D	1		1	1	1	1	1	1								1
WP1040(1A & 1B)	1		1		1	1	1	1								1
WP1040-1B	1		1	1	1	1	1	1								1
CDO3693	1	1	1		1	1	1	1								
1-3S-11B	1	1	1		1	1	1	1	1							1
1-2-DB-21A	1	1	1		1	1	1	1	1							1
CC02836C95400	1	1	1	1	1	1	1	1					$\boxed{1}$			1
CC04513	1		1	1	1	1	1	1	1							1
024-47-30-1032CF	1	1	1	1	1	1	1	1	1							1
CC04513LT2	1	1	1	1	1	1	1	1	1							1
CC04513LT3	1	1	1	1	1	1	1	1	1							1
CC02771	1		1	1	1	1	1	1	1		1	1	1			1
21289-1WC6	1	1	1	1	1	1	1	1	1		1		1			1
UB4567B	1		1	1	1		1	1	1			1	1			1
21389-18M	1	1	1	1		1	1	1	1							1
1086-5-4	1	1	1	1			1	1	1							1
UB4568A	1	1		1			1	1	1		1	1				1
UB4567A	1	1		1			1	1	1		1	1				1
CC02450	1	1					1	1	1							1
CD03700	1	1					1	1								1
CD03699	1	1		$\boxed{1}$			1	1								1
WP1040 (1A & 1B	1							1								1
WP1040-1A	1		1					1								
WP1040-1C	1		1					1								
WP1040-1E(1)	1		1					1								
WP1040-1E(2)	1		1					1								
064-18164-000	1									$\boxed{1}$						1
EVNBY00109302	1			1												1
EVNDBY0010920z	1			1												1
NP244811RLI	1			1												1
6X15HCX56AX2	1															1

Attachment A

Table 8 indicates that clear-cut groups of work-centers and non-overlapping part families do not exist. However, both Table 8 and Figure 2.18 suggest that the following work-centers – Dimensional Inspection (W/C # 7), Grinding (W/C #6), Sketch (W/C #10) and Welding (W/C #11) – are heavily utilized by a significant portion of the entire product mix that MCS handles. Therefore, in the short term, while more detailed group technology analyses are conducted to segregate the castings into families, MCS management should pursue all other feasible strategies – Theory Of Constraints, Setup Reduction, Time Studies, Work Methods Improvement, Mobile VT and hand held MT (inspectors go to where the big heavy castings are located instead of having the castings moved to the Inspection department), “right-sizing” of material handling to reduce reliance on the use of bridge cranes in the Upgrade and Inspection departments – to maximize the velocity of cash flow. Alternatively, as Avi Goldratt would say, Maximize Throughput, Minimize WIP and Minimize Operating Expenses!

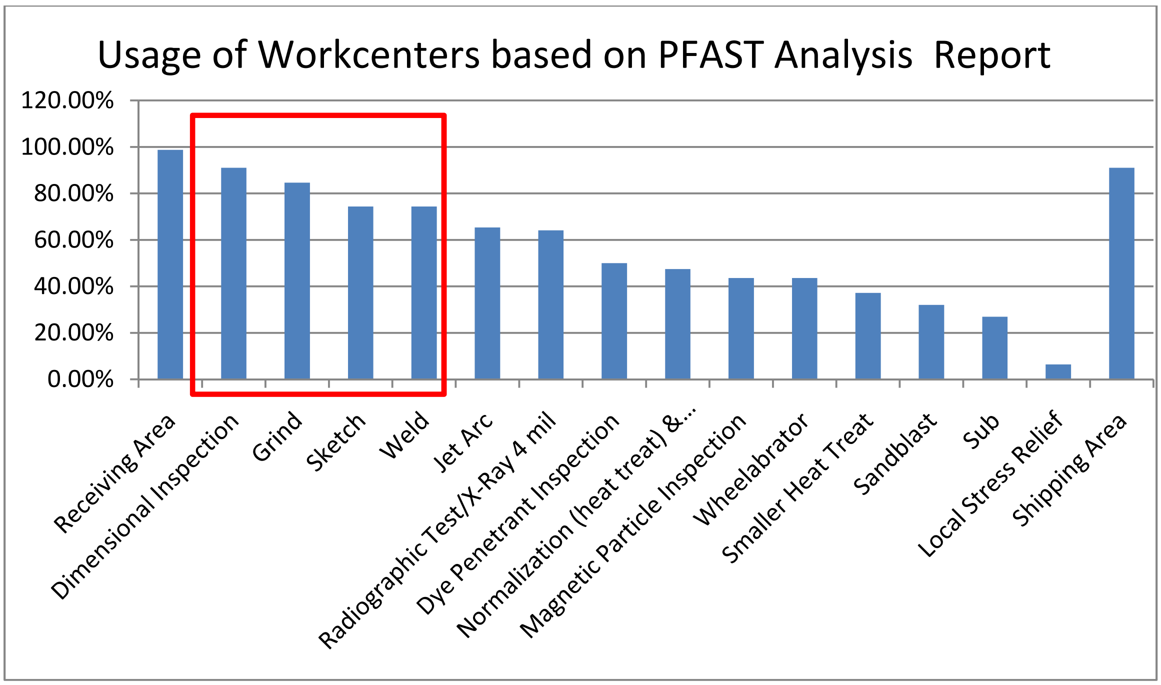

Figure 2-18 Work Center Usage

2.2 Physics Based Solidification and CAD Software Tools

While conducting Best Manufacturing Practice Enterprise assessments in support of shipbuilding operations, Willcor engineers surveyed operations that used cast components and the foundries that produced those components. As part of this work, the Willcor team determined that the use of software tools in pattern and mold design a critical element in the achievement of superior quality. The Philadelphia Naval Foundry’s implementation of these tools significantly improved their 1st time cast component quality. The team also observed that foundries that did not use these tools had more issues with 1st time quality. The Willcor Best Manufacturing Practices Enterprise team determined that the use of software tools for pattern and mold design was an industry best practice.

An outline was established that included parameters and conditions necessary for the successful implementation of software tools to aid pattern and mold design at small foundries. This included:

- Identify personnel with credentials and background suitable to learning and using sophisticated engineering software tools
- Train personnel in the use of 3-D CAD software tools which can integrate with physics based solidification suites
- Put the 3-D CAD software into regular use in the molding processes
- Develop the ability to use the 3-D CAD software as the basis to develop Computer Numerically Controlled routines for the manufacture of patterns
- Train MCS personnel in the use of a commercially available physics based solidification software suite
- Validate the physics based solidification software in the cast shop though the use of test pouring
- Make process changes
    - Bidding and sales operations request digital renderings of cast components
    - Integrate software tools into the core operations of the cast shop and the marketing operation

The procurement of software tools to aid pattern and mold design is expensive. The use of these tools requires additional expenditure of technical man-hours. Consequently, a cost analysis is required and should consider the following investment and benefit areas:
<u>Investment:</u>

- Hiring and training appropriate personnel
- Procurement and maintenance of 3-D software
- Procurement and maintenance of physics based solidification software
- Engineering/technician time required to produce pattern and mold designs for a cast component

<u>Benefits:</u>

- Reduced cost of patterns with 3-D CADS drawing driving the use of CNC routines
- Improved 1st time quality of castings which reduces upgrade work content/cost and cycle time
- Improved schedule compliance and resulting improved customer satisfaction

The MCS decided not to conduct this task as originally proposed due to staff loading concerns and also the question of the return on investment given the small production runs of each potential mold modeled. The task was partially completed and successful in that an engineer was hired who BMP had trained in CAD tools. This placed MCS in a position to use solidification modeling tools on their more challenging castings with an outside provider on an as needed basis.

2.2.1 Assessment of MCS for the Introduction of Software Tools

The Willcor team worked with MCS management to develop a plan to implement Physics based software and 3-D CAD software tools. Following the decision not to fully implement "in house" the physics based software tool an engineer was hired by MCS who BMP had trained in CAD tools. This and the following steps allowed the use of this capability on their challenging castings. Key cast shop personnel were integrated into a team to execute the key activities outlined below.

2.2.1.1 Implementation

In order to familiarize the new-hire engineer with casting operations, a process map for the cast shop was developed. MCS and Willcor engineers walked the cast shop floor and visited the various work centers. At each work center, the mechanic was interviewed and process steps were identified. The entire process was entered into the IGRAPHIX software suite. This dual use document was employed as a training aid and to provide an overview of operations for the targeting of process improvements.

The new MCS engineer had previous experience with 3-D software and basic knowledge of the 3-D CAD SOLIDWORKS software package. He initiated the use of this tool and attended SOLIDWORKS training at the Columbia, MD facility.

With the new engineer in the lead, MCS started to employ 3-D CAD software to create digital renditions of patterns. To ensure the utility of the 3D output product, the Willcor team visited a local pattern maker that was working from a drawing produced using the SOLDWORKS software package. The pattern maker had positive feedback.

MCS had a third party perform a solidification study of a digital rendering of a pattern drawing produced by their personnel. The casting was viewed as one of their more challenging. The MCS subsequently noted that this casting effort was successful. The MCS has continued this practice of using third party solidification evaluations of problematic cast components on a case-by-case basis.

During the execution of this project element, MCS cast shop management expressed a desire to move its planning and scheduling operations to Manufacturing Resource Planning (MRP) software. They identified the ProfitKey software suite, utilized by the upgrade facility, as the target system. To support this effort, the Willcor Team worked with the appropriate cast shop personnel to create a process map that will assist in the development and transition to the MRP system.

Most large modern manufacturing operations, such as shipyards and their first tier suppliers, regularly create and use digital drawings of components. Providing component drawings as digital renditions would significantly reduce the cost of creating pattern drawings. Both the cast shop and the Willcor SME requested digital renditions of cast components to facilitate the use of CAD software. A positive response to these requests has not yet been received, but it is recommended that this be followed up on in the future, as it would appear to be in the best interest of all parties.

2.2.2 Continuing Improvements

Going forward, it is recommended that the MCS continue on the current path of outsourcing solidification modeling as needed on more challenging castings while

continuing to request customers (shipyards and their 1st tier suppliers) to obtain 3D product representations.
As of this time the MCS has used the third party solidification modeling on two castings which they considered successful. As experience is gained using the outsourced modeling capability, data will become available which can be used to make a case as to whether there is an adequate return on investment to bring the capability “in house.” The up front software and personnel training costs to develop an organic capability is available, however there is not yet enough data on hand to determine the amount of Upgrade work content that could be avoided by bringing the capability fully in house and expanding it’s use to a wider range of the product line.

2.3 Technical Process Improvements

A thorough assessment of cast shop operations and processes initiated this phase of the effort. The review was a combination of factory floor observations by a foundry expert and audit of written procedures in use by the MCS cast shop department which included operation sheets, procedures, process conformance, casting techniques, component finishing techniques, testing, and quality assurance processes. Mr. W. L. Mankins of Metallurgical Services, Inc. (METALANS@CS.COM) was the team’s Subject Matter Expert that conducted the assessment.

The goal of this review was to identify Best Practice operating processes and technologies applicable to the cast shop operations that are “off-the-shelf” cost effective solutions.

2.3.1 Cast Shop Floor Assessment Conducted June 2009

2.3.1.1 Introduction

The overall objectives of any Melt Shop improvements are to produce defect-free castings the first time a pattern is made and every time thereafter. This is imperative when one considers the critical applications where Regal Cast parts are used. It is human nature to resist changes in our habits or the way that we do things, however, we must be willing to embrace new ideas or concepts to compete and meet customer needs. Improvements or changes of any type remove us from our “comfort zones” as we move in directions that do not guarantee immediate positive results.

It is recognized that changes or improvements in operations come at a cost, simply stated, “there are no free lunches,” so the changes proposed will be discussed in terms of cost and projected savings that would come from modifications in equipment or procedures recommended.

This report will investigate process steps required by the cast shop operation, from receiving a melt order to the shipment of a quality casting to the MCS upgrade facility for finishing and delivery to the customer.

2.3.1.2 Discussion

The cast shop operation has a product mix that consists of carbon/low alloy steels, stainless steels, and high nickel based alloys. All stainless steel alloys are normally melted in an Induction Melt Furnace and processed through the Argon-Oxygen-Decarburization (AOD) vessel to decarburize and desulfurize them. Additionally, nickel-base and cupro-nickel alloy castings are made by melting and deoxidizing these alloys in the Induction Melt Furnace.

2.3.1.2.1 Overview of Processes

The processing steps from receiving an to the shipment of finished castings to PRL will be discussed in the order they are performed. The comments made and recommendations proposed are based on observations made during the visit to Cast Shop operations in June 2009, known best practices, and the experiences gained through many years of metal casting.

It should be mentioned that the operation of the foundry is well conceived and runs smoothly, but there are changes that can improve the efficiency of the operation and the quality of the castings made. Processing steps will be listed, discussed, recommended provided, and benefits projected.

2.3.1.2.2 Control of Material Melt Weights

OBSERVATIONS

On June 3 casting operations that produced components made of Stainless Steel grade 410 (CA15) castings. This operation is typical of those observed during the assessment period.

Shop personnel melted 5000 lb in the induction furnace. The chemistry was adjusted and 3000 lbs was tapped to the ladle. As shown in Figure 2-19, two impellers of approximately 1100 lb each and test blocks were poured. The remainder was pigged for revert. It can be seen that the pig is approximately 24 in tall, indicating it would weigh approximately 1600 lb. It is not known if any material was poured back into the furnace from the ladle.

The induction furnace was recharged to a total weight of 5400 lb. It is not known if the additional charge added was weighed or estimated. After melting this charge, the furnace was tapped and transferred to the Argon-Oxygen Decarburization Vessel (AOD).

An additional 2600 lb. of punchings were added to the AOD and melted for a total charge in the AOD of 8000 lb. After decarburization, desulfurization, adjusting the chemistry of the heat, and heating to the tap temperature, it was tapped to the ladle.

Two valve bodies of approximately 3400 lbs each were teemed into the molds and test blocks were poured. The remainder was pigged for revert. A second pig was filled with approximately 1600 lb of revert and an additional 200 lb revert was poured into a second mold. The slag and small amount of metal in the ladle was poured into a slag dish estimated at around 200 lbs.

The revert from the second pour of this heat would be estimated at nearly 2000 lbs. It can be seen that the two pours made from this heat resulted in about 3600 lbs of revert. The total furnace charges for these two heats was estimated at 11,000 lbs plus small additions made to the AOD.

The revert produced 32.7% (3600/11000 x 100%) as a percentage of charge weight.

This amount of revert produced is excessive and indicates charge and addition weighing procedures need to be implemented to reduce this amount. This clearly points to the need for weighing all materials used in the melting and casting processes.

Prudent use of revert materials has a direct effect on the cost of production of all alloys cast. Revert material has already been purchased so using it is like "free" charge metals. Each pound of revert used replaces a pound of punchings or other raw materials that must be bought which adds "new" dollars to the cost of producing the castings.

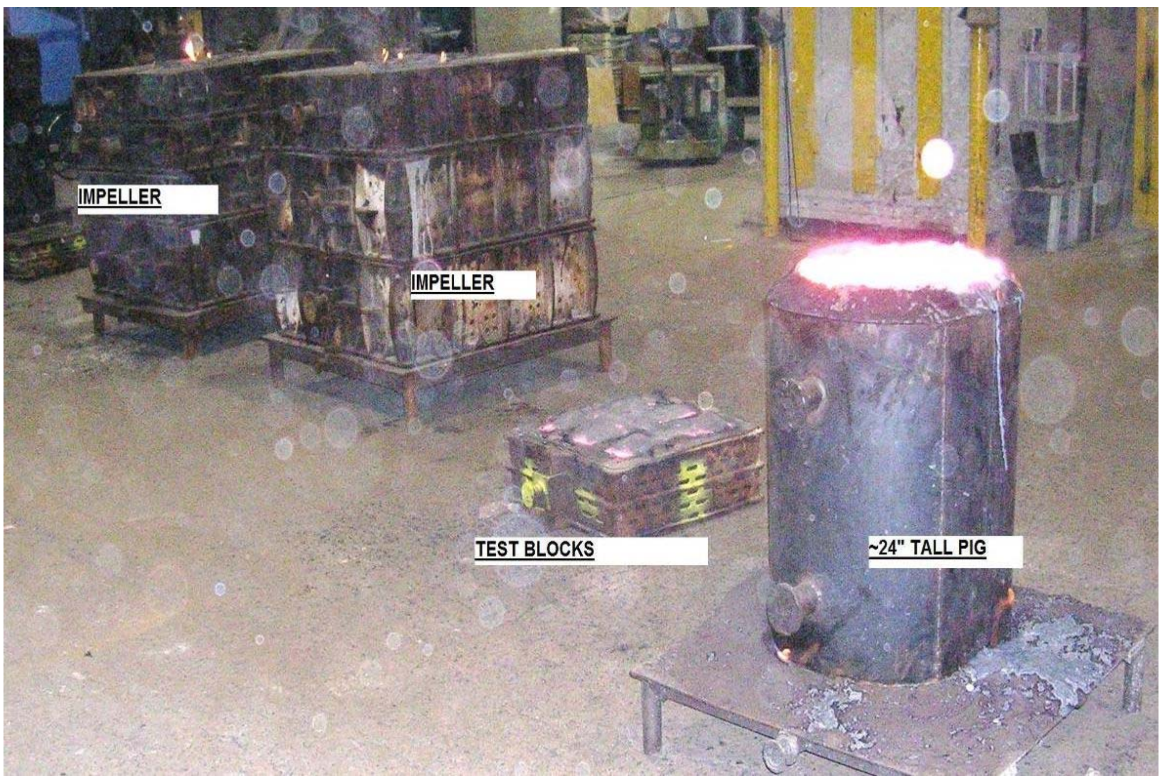

Figure 2-19 Melted 5000 lb Induction Melt Furnace tapped out with 2 1100 lb impellors, 1500 lb test block and 1600 lb pig

Best Practice Planning Processes

Weekly Melt Plan:

Attachment A

This document was generated by cast shop management for the week and is a primary planning document for cast shop operations. The plan should include the following information:

- States the alloys that will be made
- States the castings that will be made, the number of each and their weight
- How much revert and raw material will be needed for the melt program
- The required patterns
- Location of the pattern, local or distant storage
- The required molds and cores that will be needed and when
- The sequence of melting
- The number of heats produced per day

Charge or Melt Sheets (Heat Sheets):

- Alloy
- Special chemistry requirements
- Number of molds to be poured
- Indication if heat will use only the Induction Melt Furnace or if both Induction Melt Furnace and the argon-oxygen-decarburization vessel will be utilized.
- Special instructions
- Weight of the cast components
- Additional cast weight for Risers, Sprues, and Test Blocks
- Weight estimated for Induction Melting furnace losses,
- Weight estimates for process losses; ladle losses (if AOD used), AOD losses, Slag-off losses, Teeming ladle losses.
- Additional weight for slag pot after teeming of molds and cast bars estimated from the number of castings made or total weight cast.
- The Total Charge calculated from the above
- Melt weight required for the Induction Melt Furnace
- Additional weight to be added in AOD

RECOMMENDATION

Develop weekly Melt Plan and Charge /Melt or Heatsheets with the additional information recommended above designed to reflect the complete heat history including the materials and amounts used in making up all furnace and AOD charges and additions. Weighing tickets for all materials need to be included in the heat history for all heatsheats produced. This This history of all heats needs to be archived to provide traceability of each casting sold for critical applications.

Figure 2-20 Crane Hook arrangement as ladle is poured into add vessel

OBSERVATION

There did not appear to be an effective use of revert within the casting operation. Platform scales in the additions room are available and fitted to record weights (not demonstrated) or can be made to record and print weights. Crane scales are available but would need to be modified to record amounts weighed and would also need to be fitted with a heat shield for use when weighing hot ladles and contents. Figure 2-20 clearly shows that there is enough room between the crane hook and the ladle for installing a crane scale. The heat radiating from the ladle demonstrates the need for a heat shield to protect the scale electronics. Mechanical scales have been observed in other foundry operations

Figure 2-21 shows a portion of the revert material stored outside the foundry. The iron oxide (rust) on many of the pieces indicates that it has been exposed to the weather for an extended period of time. The value of the material stored in this area was significant.

Figure 2-21 Revert storage outside the MCS Cast Shop

The large pigs shown in the foreground are excess material that remained in the ladle after pouring the castings and test blocks. The pigs, approximately 17 inches in diameter weigh around 67 lb per inch of height. AA 24 inch tall pig would weigh ~1600 pounds. If the total furnace weight is 8000 lb, then the pig weight is approximately 20% of the melted weight which is considered excessive.
This pig weight is the “insurance” that the cast weight will be sufficient to adequately fill all of the molds and the test blocks. Excessively large pigs cost money and result from not weighing the amount of metal going into the Induction Melt Furnace and the AOD as additions to adjust the alloy chemistry or to deoxidize the heat.

BEST PRACTICE

System control of the amount of revert produced can be accomplished through the use of planning documents such at the Heat/Charge Sheet discussed above and by weighing materials during the melting process.

Revert must be re-consumed at approximately the same rate that it is generated to preclude increasing non-value added revert inventory. A second best practice in this area is the consumption and reuse of revert produced from pigging as well as the risers, sprues and runners that are cut off as scrap from the cast component. The post cast component clean up process should include several steps

- Revert from all sources, risers, sprues, runners and pigged material, must be weighed
- The revert must be marked with alloy and weight
- Organized storage of revert must facilitate the use of these materials

RECOMMENDATION

The MCS cast operation should develop processes to minimize and effectively utilize revert materials. To clear the revert inventory shown in Figure 2-21, each item should be identified as to alloy. For items where the alloy is in question, that item must be alloy checked (analyzed).

The MCS cast operation should organize the revert storage operation to facilitate the easy use of this material.

2.3.1.2.3 Temperature Measurement and Monitoring:

Temperature control in all foundry operations is necessary. Temperature control starts with furnace procedures each time a heat is melted. Casting quality is directly dependent on the temperature of the metal during the entire melting and casting processes to ensure proper metal fluidity, oxidation and de-oxidation, and solidification.

OBSERVATION

The cast operation of the MCS uses immersion thermocouples to determine bath temperatures in the Induction Melt Furnace and the AOD vessel.

There is not a capability of measuring stream temperatures of metal being tapped from the furnace or vessel, or the temperature of molten metal being teemed into molds.

The quality of the casting produced has a strong dependence on the temperature of the molten metal poured into the mold. The amount of superheat, heat content as a function of temperature above the melting point of the alloy, influences the fluidity of the molten metal. A number of critical casting parameters are directly influenced by the fluidity including:

- Fill rate which determines the rate at which metal fills the mold, particularly in thin or intricate passages in the mold.
- Solidification time which controls metallurgical quality of the casting, coarse structure for longer solidification time and fine cast structure for material which solidifies or is nearly chill cast.
- Surface quality of the casting (amount of surface defects produced.)
- Escape rate of entrapped gases which contribute to porosity is also temperature dependent since lower temperatures do not provide as much time for gas bubbles to rise from the liquid soon to be solidified as metal.

Obviously, the metal being teemed into the first mold is hotter than that being teemed into the last mold of a sequence. Determining the pour temperature is a critical quality parameter.

High tech consumers such as the navy nuclear power, civilian nuclear power, and process industries of foundry products are either demanding full disclosure of adherence to established manufacturing process steps or they will be requiring this documentation in the near future. Foundries will be mandated to show that written procedures are being followed. It will be necessary to continuously monitor and also document the measured values which are relevant to individual product quality. Temperature measurement is so connected to product quality that it will be a required physical parameter to record and archive for each heat produced.

Best Practices

Temperature monitoring at each step of the casting process is critical to ensure the quality of the product.

Measuring and recording the metal temperatures at critical times during the IM furnace operations, during transfer of metal to the AOD vessel, during the AOD processing procedures, and during tap and teeming operations are quality assurance steps. The proposed Heat History sheet should include lines or data boxes for the measured temperatures to be recorded. Compilation of this thermal data also becomes part of the shop floor process control.

State of the art, hand held, optical infrared pyrometers are available for foundry use wherein accurate readings of temperature can be collected on a continuous basis. High temperature pyrometers for measuring molten metals cost about $3000 , depending on the features that are included in the design of the equipment. Low temperature pyrometers (RAYTEK MT-4 or MT-6, with Laser guide and range to ~ 1000F) can be purchased for less than $100.00.

Recommendation

Hand held infrared optical pyrometers are readily available and have been identified. Arrangements need to be made with one or more equipment suppliers to conduct field usage trials at the MCS cast operation. Once the preferred equipment has been selected, it is recommended this be purchased and used.

2.3.1.2.4 Mold Drying:

The need to heat and dry all molds before casting is a fundamental principle of casting doctrine. Mold heating in foundries producing premium castings has been practiced for many years.

Observation

The cast operation has two ovens on site, Figure 2-22 that are used for Cu-Ni castings and sparingly during other operations. These ovens are natural gas heated and do not support the internal air flow within the mold.

An extra lift and move using a fork lift is required to utilize these furnaces. The extra move increases the risk of interior damage to the mold.

The ovens are large enough to accommodate molds up to 60 inches square or four smaller molds. The largest molds are problematic to maneuver into and out of the ovens.

Figure 2-22 Mold Heating Ovens on the Floor of the Melt Shop

A provider of mold driers stated they have supplied equipment to a number of casting operations including Philadelphia Naval Foundry, Newport News Naval Shipyard foundry, Pascagoula Mississippi Naval Yard, St. Mary’s Foundry in Ohio.

This provider of mold heaters provided the following insights:

- As a result of mold heating, scrap reduction has been reported especially when chills and mold coatings are used.
- Thoroughly dried molds obtain maximum strength from binders prior to casting.
- Heating and drying molds eliminates variability in the temperature and retained moisture due to changes in atmospheric conditions.
- Mold heating eliminates variability in vapor due to the out-gassing of glues and cements used in mold preparation.

Hot air is used to heat all surfaces of the mold to 250F. The higher interior temperature is advantageous in pouring castings with thin sections such as impeller blades/vanes. Metal flow is more uniform and the solidification time of the casting will be more uniform and can be predicted more accurately using available software (physics based solidification). More uniform solidification parameters aid in more uniform mechanical properties in the finished casting.

The MCS Upgrade facility has identified gas as a recurring reason for scrapping castings. Sources of gas porosity include moisture within the mold and/or out gassing glues and cements used as binders for the sand. Other sources of gas are the incomplete de-oxidation of the molten charge in the AOD or re-oxidation that occurs during tapping to the ladle or teeming of the metal into the molds.

BEST PRACTICES

Mold heating and drying prior to the pouring operation is a critical process and its success has been demonstrated at the Naval Foundry Propeller Center located in Philadelphia, PA.

RECOMMENDATION

The need for mold heating has been positively identified and the implementation of mold heating can be initiated without a capital expenditure by using existing ovens on the Melt Shop floor. This will provide a proof of concept and permit costing studies to be conducted that will justify purchasing additional mold heating equipment.

It is recommended that the existing mold ovens on the shop floor be used to explore and verify the benefits obtained by mold heating. Molds can be loaded into the ovens with a tow motor. They can be heated for a specified time and temperature and then moved into position for casting when needed. A heating temperature of 250F for two hours would be used and the molds would be removed from the ovens just before teeming. A cover needs to be placed over the pouring cup and risers during heating. Comparisons of identical castings made from molds that were heated before teeming and those produced using present day practice would need to be made. Melting/furnace practice must be held constant during these experiments with close control of teeming temperatures for all of the castings made in the experiment so the only variable to be measured will be mold heating. Temperatures can be measured with the proposed optical pyrometers that have been suggested for purchase. A MiniTemp (low temperature) pyrometer is capable of providing accurate measurement of the heated mold temperatures.

Additional mold heating capacity can be obtained from companies such as CASTEC.. One purchased mold heating station with a manifold and flexible ducting would be capable of heating a single large mold or multiple smaller molds.

Figure 2-23 Possible Mold Heater Station Area

There is adequate space for a portable heating station between the existing ovens and the melting platform as is shown in FIGURE 2-23. The area identified is presently used to store raw material such as iron punching. These drums of material are palletized and can be moved by tow motor, therefore, they can be placed in any convenient location in the proximity of the melt furnaces.

2.3.1.2.5 METALLURGY AND PHYSICAL CHEMISTRY OF INDUCTION MELTING FURNACE AND ARGON-OXYGEN DECARBURIZATION (AOD) PROCESSES:

The quality of the molten metal introduced into the mold is determined by the de-oxidation practice used in the furnace and the ladle. It is imperative that the supervising melt shop personnel as well as the melters know and understand de-oxidation, process of removing gases, primarily oxygen, and practices for the many alloys that are produced.

OBSERVATION

Carbon, low alloy, and stainless steels that are initially melted in the Induction Melt furnace and ladled to the AOD vessel have additional metallurgical requirements. The AOD process is intended for decarburization, desulfurization, reduction of oxided elements back to the metallic state, and final de-oxidation of the heat. It can be utilized to melt additional charge, however, it is not a melting furnace since it has no source of externally supplied thermal energy. An exothermic, heat producing, reaction between aluminum and oxygen raises the temperature of the molten bath to more than 3000F and melts the material added as extra charge. The addition of charge metal cools the molten bath to the desired temperature range between 2800°F and 2900°F

All of the reactions that occur within the AOD vessel are predictable and obey the laws of physical chemistry and metallurgy. This is the reason that the operation of the AOD process can be programmed using the computer and give reproducible results from heat to heat of the same alloy and from one alloy to another.

The comprehensive hardware and software program installed on the MCS cast shop AOD computer includes the PRAXAIR Intelligent Refining System (IRS), a sophisticated program for refining steels.

PRAXAIR wrote a paper discussing operating experiences using their IRS to control the AOD vessel. The comments below are quoted from that report.

"IRS makes the system easy for the operator to use. It integrates operator responsibilities (blow program, alloy additions, data management) into a single system. Minimizes operator data entry, to reduce errors and to improve productivity. Automates many tasks to reduce operator error, enforce reproducibility, and increase reliability. It promotes operator-to-operator consistency and standardizes best operating practices. It improves process efficiency by optimizing:

- Temperature–attain temperature aims while avoiding over-temperature conditions.
- Carbon removal–maximize carbon removal rate.
- Reduction of alloy elements–minimize metallic oxidation.
- Inert gas cost—maximize nitrogen use instead of the more costly argon gas use.
- Refractory consumption– manage slag composition and tuyere protection control.

- Alloy cost–Use a least cost program that includes slag and reduction alloys in the calculation."

This program automatically handles a product mix that includes carbon, low-alloy, stainless, and nickel-base alloys. It incorporates automatic data collection and management to allow reporting and off-line process optimization by the metallurgical staff. Aids in maintenance and provides on-line help in maintaining the system. It provides remote monitoring and problem resolution via modem or network access. Provides a platform for integration of new systems and technologies to further improve stainless steel processing. Full use is made of graphical interfaces. The IRS system even provides a simulation mode for training and demonstration.

Due to the wide variety of alloys and complexity of the operation, management should set aside some time for ongoing training. The training and simulation mode should be taken advantage of as appropriate as part of ongoing refresher training. If the physical chemistry and metallurgical features of the above program are not fully understood by all melt shop management personnel as well as the AOD operating personnel, a training session or tutorial on the system would be a high priority.

BEST PRACTICE

Training programs to ensure personnel can operate equipment safely and effectively are a core responsibility of management.

RECOMMENDATION

Personnel in the Melt Shop (Management and Operating) are critical to successful operation of the foundry and should participate in periodic training sessions. A full day effort with periodic follow-up is a good investment of company resources. This training would provide personnel with expanded knowledge and technical understanding of the AOD process and operation, but also enable management and operators to discuss operating procedures or problems that may occur.

PRAXAIR can provide an expert to teach such a tutorial and the cost is estimated to be more than offset by the knowledge gained which would support improved operations and also analysis of root cause of problems when they occur. A one day training session was provided by PRAXAIR as part of this effort. The training covered melting processes and AOD operations. Additional training sessions with PRAXAIR or using the system's embedded training feature could be held on a Friday outside of production hours. This training would be particularly valuable for a new employee such as Mike Ecenroad (Mechanical Engineer, with little metallurgical background), and Donnie Kirkwood (AOD vessel operator, a potentially very valuable employee, who needs a good metallurgical understanding of what is happening in the process, and what certain process steps accomplish).
A tutorial in the metallurgical understanding of the Induction Melt furnace would be beneficial and should be included in future training efforts.

Given the complexity of the processes associated with the wide range of metal types, internally lead (or outsourced) periodic refresher training for all personnel would be beneficial to the company.

Appendix A

Transitioned Project Elements from Internal MCS Efficiency Memo

"MCS can't continue to do business the way we have in the past in order to survive well into the 21st century."

The above quote has become MCS's mantra, as last year we began brainstorming and worked with consultants to implement lean manufacturing. Our consulting team was headed up by BMPCOE/WILLCOR, who obtained funding to head up our project from the Defense Logistics Agency (DLA) under the Industrial Base Innovation Program Fund. (wvvw.willcor.com) (www.bmpcoe.org) MCS's goal, which is reflected in the attached newsletter page, is to change our corporate culture in order to meet our customers' expectations of quicker deliveries, through better efficiencies, reduced cycle time, and better initial quality. Initiatives include tracking performance through metrics, discovering areas of waste, attaining more feedback through all levels in the organization, changing shop work flow and processes, and identifying departmental constraints. This is being combined with a significant capital loan to purchase more efficient equipment, reorganize shop floor layouts, and expand the MCS facilities.

More specifically, changes being implemented, which will positively impact our deliveries for the next Virginia Class and CVN order, are highlighted below:

- MCS is in the process of reorganizing our shop floor. This entails creating three new work cells. The first two include combining a welding and grinding booth, and the third one will be adding a combination MT/PT booth in the weld area. We also intend to push out part of the wall between Inspection and Upgrading and add a turntable to move castings between the two departments. As an example, currently about 75% of the castings go to the next processing stage via forklift through a 9 foot opening. In addition to the above, we will be adding a new electric lift pallet truck, adding a jib crane, and expanding our existing cranes in both Inspection and Upgrading. The combination weld/grind booth will enable us to perform both processes in the same cell. (It is much more efficient to move a worker versus the casting.) The magnetic particle/dye penetrant booth located in the Upgrading area will also not only relieve a constraint in the Inspection area, but will prevent the castings from having to be moved back to Inspection. All these modifications will alleviate numerous bottlenecks on the shop floor. Furthermore, all work areas are being redesigned with feedback from our co-workers to make them more efficient.

- MCS intends to expand our shop to add a separate Shipping and Receiving area. Currently, this function is done in an already too crowded Inspection area. Not only will the expansion free up floor space, but it will enable Inspection to turn around castings more quickly, as interruptions shall be minimized. The location of the expansion will also provide for a separate casting marking area next to the heat treat furnace. There will also be a staging area, which will alleviate many of the castings sitting in the middle of our shop floor.

- The building expansion at MCS also includes a new maintenance area located next to the existing one. This will expand our current area which is exceedingly small, given the size of our operations. It will also enable Maintenance to work on vehicles or equipment rebuilds inside the building, which has been an ongoing inconvenience for the department. Furthermore, all of the Maintenance Department tools and supplies will be consolidated in one area. Currently, due to space constraints, they are spread throughout the kingdom. This will make this department more efficient, and better able to focus on equipment maintenance and repairs. This should reduce the amount of down time due to equipment problems, and in turn improve delivery times.

- As stated previously, MCS is in the process of purchasing another Magnetic Particle Machine. Aside from relieving bottlenecks, this will enable us to add an additional 2,900 hours of MT/PT to our shop on an annualized basis.

- MCS recently purchased a Faro-Arm for usage in our Inspection Department. This increases our dimensional capabilities in the Inspection Department which is also considered a bottleneck. Additional benefits include the arms programming capabilities, and the fact that a calibrated dimensional table is not required for its usage. Thus, the arm can also be utilized at the machining facility if needed to alleviate constraints in that area. Again, more efficient, which means quicker deliveries.

- MCS is purchasing a new digital RT Processor, which will enable us to choose between digital imaging or RT film as warranted. The main advantages of digital imaging are shorter exposure times, and images can be sent via e-mail. MCS will be able to use digital exposures for certain commercial customers, all quality and cut-out shots, and shots necessary to set up techniques, which will make our RT Department more efficient. Obviously, original film exposures will still need to be utilized on final exposures for all military work, but more man hours will be available for completion. Also, if the nuclear navy decides to go digital, MCS will be at the forefront. Installation of the machine will require some shop modifications as a separate reading area with a positive air flow will need to be created.

- Recently MCS completed a massive overhaul of our heat treat furnace and added additional programmable capabilities. Although this doesn't offset the costs of the temperature ramp up requirements recently imposed upon us, it will drastically reduce potential errors. (As a side note, this change has now unfortunately precluded us from running heat treats on weekends.) It is very user friendly, which means more of our worker's will be qualified to run the furnaces.

- MCS is also upgrading all of our welding machines, which date back to the 1970's. The machines are more efficient, particularly when it comes to mig welding. This past year MCS has made a more concerted effort to utilize more MIG and TIG welding versus stick welding. We also have begun in-house welder training, hired a weld expert in our Q.A. Department and joined the Edison Welding Institute, a leading technology organization dedicated to welding technology (wvvw.ewi.orq). Although not cheap, they are only a phone call away to answer and/or research any issues we may have.

- Another improvement targeted for MCS includes expanding ProfitKey, our software program, to include scheduling, and bar coding. This will not only track job times more efficiently, but replace our arduous manual scheduling system. Upon successful implementation, we intend to utilize the program in our remaining three facilities.

- MCS is also better managing our queue and limiting the amount of work directly on the shop floor. Job staging areas have been reduced to 16 hours of work with a future goal of 8 hours. For the first time in our history, every co-worker now knows exactly which casting should be worked on next.

- Effective January 3, 2010, MCS started a 3rd shift, which enables us to operate a 24-hour day. Currently the shift has a Radiographer and three Grinders. It is our intent to also hopefully add an Inspector and Welder to this shift.

- The MCS foundry, has also adopted lean manufacturing. The facilities floor space is very limited, but through the utilization of additional shelving, redefined work area, and an overall team effort, the shop appears to have expanded! In the past year we also ramped up to two heats a day versus one on an as needed basis.

- MCS foundry has recently been using an outside consultant to utilize solidification modeling software modeling on jobs which have been particularly problematic. To do this MCS has to convert the existing drawing to a CAD/CAM one, which is very time consuming and costly. If MCS could attain CAD/CAM drawings from our customers, we would go ahead and purchase the software program. Until that time, we will continue to use our outside consultant on an as needed limited basis. Preliminary improvements in initial quality have been positive, which reduces processing time at MCS Upgrade facilities.

- Our consultants also spent a tremendous amount of time at the MCS foundry working on processes as well as better documentation. Among some of the issues addressed were recording pour temperatures by mold, determining optimal charge weights, preheating molds more consistently, and tracking additional information by heat. This should lead to more consistent casting quality.

- MCS machining has added VT and PT capability at their location. This will enable them to perform inspection on components and assemblies, eliminating part transport time to MCS . It can also be utilized for overflow work for MCS if needed. Overall benefits will be improved part control, better efficiencies and quicker lead times.

- All of our divisions are putting more emphasis on training. We have worked with the local community college to develop programs based on our needs. As an example, last year we sent 25 of our coworkers for off-site training on geometric tolerancing. We are also sending many of our employees to specialized courses across the country, including the American Foundry Society. Internally, we intend to develop a lean manufacturing continuous improvement training program for all of our co-workers on an ongoing basis.

MCS has had a challenging two and a half years. We had our two Senior Managers retire and changing a corporate culture is not easy. The good news is, as a company, we finally have a stronger, more cohesive team, and are beginning to see the benefits of our philosophical redirection take hold. We are investing significant dollars and time in our organization in anticipation of future growth, needed to support our investment. MCS is committed to staying a step ahead of our competitors, while improving deliveries and maintaining prior quality expectations. Future challenges will include higher energy costs, a volatile commodities market, and more government mandates. Our goal is to pro-actively tackle these issues and become the supplier of choice, as not only the most vertically integrated sand foundry in the country, but for individual machining services as well.

In closing, it is imperative MCS work closely with their customers to address areas of concern. The metals industry is exceedingly difficult and open communications, flexibility, and mutual co-operation and respect is important. Meetings such as the one with Electric Boat are very helpful. We appreciate the opportunity to provide you with the above information, and encourage you to share it with Electric Boat and Newport News. We also look forward to a mutually prosperous relationship in the future.

President, MCS, Inc.

Attachment B

Maritime Cast Shop Integrated Improvement Plan

Stateline Industries, INC

Prepared By:
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Michael Delaney
Albert Lang

Understanding future effects of today's decisions

ACKNOWLEDGMENT

The Willcor Team would like to acknowledge the superb accomplishments of all of the team members that contributed to the overall success

Stateline Cast Shop Personnel

Mr. William Mankins

Dr. Shahrukh Irani

Mr. Rajesh Mantena

EXECUTIVE SUMMARY

The Maritime Cast Shop Integrated Improvement Plan, sponsored by the Defense Logistics Agency's Industrial Base Innovation Fund, resulted in reduced cycle time, lead time, and significant increases in productivity at Stateline Foundries, Inc. (SLF). The Willcor Team conducted the effort at this Maritime Cast Shop between Feb and Mar 2010.

SLF is the supplier of cast components used in ship clutch and brakes supplied by Eaton-Airflex for aircraft carrier and surface ships. After consultation with Eaton-Airflex and SLF, the Willcor Team developed a focused effort targeted at reducing lead time and improving 1st time quality of the cast products. The effort consisted of Job Shop Lean initiatives coupled with improved foundry processes. The goal was to provide off-the-shelf cost effective solutions that would lead to improved 1st time casting quality and reduced cycle and lead times.

The Willcor Team has developed a unique systemic approach to improving operations in foundries vice the traditional "one casting at a time' methodology. Willcor starts with a comprehensive system assessment that targets foundry operation work processes for multiple products and product lines and develops projects tailored to the unique needs of the MCS foundry. Training on the goals and methods and principles of Lean Engineering and JobShop Lean are critical to success. Projects are targeted at constraints that limit capacity of key production elements. Solutions typically result in better understanding of what is required for an improved production process, reduced transportation and handling, and produce a positive impact on cycle and lead times.

SLF is a quality-driven, customer-responsive iron foundry specializing in prototype and low-to-medium volume production castings. SLF completed ISO 9001:2000 certification in November of 2002 and has in-house metallurgical testing capabilities using an in-house spectrograph and tensile testing equipment. SLF uses process controls and work instructions for each element of the casting process in an effort to assure quality product.

SLF produces castings ranging from ounces up to 2,000 pounds in lot sizes of one to thousands. SLF pours multiple grades of gray and ductile iron each day using batch furnaces. SLF considers the flexibility and capability to rapidly produce iron castings of various complexities, sizes and metal specifications a competitive market niche. SLF pours Gray and Ductile Iron grades include:

- Austempered Ductile Iron
- High Temperature Ductile Iron (High Silicon Molybdenum)
- Gray and Ductile NI-Resist
- Low and Medium Alloy Gray and Ductile Iron

The Willcor Team performed an initial assessment at SLF and an 8 week Job Shop Lean engagement which resulted in a 19% cycle time reduction of the largest castings produced by SLF. The Air Set Floor casting area's organization and utilization was significantly improved. Numerous Willcor Team recommendations to further reduce scrap rates were provided and are anticipated to be implemented by the company.

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1 SUMMARY

1.1 INTRODUCTION

The Maritime Cast Shop Integrated Improvement Plan, sponsored by the Defense Logistics Agency’s Industrial Base Innovation Fund, resulted in significant increases in productivity, reduction of work-in-progress, and substantially reduced cycle times that will lead to reduced casting lead time at the participating Maritime Cast Shops (MCS).

The Willcor Team’s MCS improvement methodology was applied to the SLF operation. A comprehensive system view targeted improving foundry operation business processes, work techniques, and product lines for this facility.

The project was accomplished in two phases. The first phase assessed the operation and developed a plan tailored to the unique needs of the MCS foundry. A ‘menu’ of projects designed to ensure the effective use of SLF resources was presented to management. SLF selected activities from the menu and the Willcor team formed action groups with the foundry to accomplish those activities.

The action team was composed of a foundry expert and a Willcor Job Shop Lean (JSLean) or casting technical expert. The action team studied the issue and gained insight into the SLF unique operation through the use of process mapping, brain storming, identification of constraints and identification of the desired improvements. The outputs of the action teams identified and addressed the core causes in several key areas:

- Scrap creation
- Capacity limiting constraints
- Intra-shop transportation
- Excess handling

A positive impact on cycle time, projected lead time and quality resulted from actions taken by the teams.

1.2 SUMMARY, RESULTS OBTAINED AND CONCLUSIONS

1.2.1 JOB SHOP LEAN

This segment of the project investigated, developed and deployed methods of JSLean to the manufacturing processes in a foundry facility that supplies castings to the maritime, defense and commercial sectors. The primary objective was to look for opportunities to reduce lead time and cycle time of castings by reducing non-value added foundry floor activities and the business processes supporting foundry operations. Additional goals included the improvement of quality, cost, mold making (a constraint), reduce floor space requirements, and improve the storage/movement of patterns.

The Willcor team made an assessment visit to SLF in February 2010. The product of that assessment was the decision to implement the following projects:

- **Improve efficiency of Air Set Floor operations and processes**: The Air Set Floor is where the largest molds are poured and represent the largest part of the operation in dollar sales volume. Typical Air Set molds were taking an average of almost one and a

half hours to prepare before a pour could be conducted. The primary goal of this project was to reduce mold preparation cycle time which increases throughput. A secondary goal was to gain additional floor space to increase capacity and flexibility. Reduced cycle time and increased floor space was to be obtained by:
  - eliminating unnecessary or rarely used items
  - organizing the upsets and other supplies more efficiently while bringing them closer to the technician.
- **Relocate the green sand pile**: Identify alternative locations for the reclaimed green sand pile to
  - reduce material handling times/costs and delays
  - decrease congestion in the area
  - reduce safety hazards due to back-and-forth forklift traffic
- **Improve storage of Patterns in the Pattern room**: Eliminate unnecessary patterns and systematize, through better organization, the layout of the pattern room based on usage priorities of the patterns. The goal was to reduce search and handling time.
- **Organize the Core Room**: Organize the core room by adding shelves and promoting visual management by using lean 5S methods with the goal reducing search time.
- **Increase Consumables Storage Room Space**: Using 5S and red tagging in this storage room to increase available floor space for higher priority items.

The results obtained showed that the proper application of JSLean techniques have a marked effect on a foundry in a relatively short period of time. After an 8 week Job Shop Lean engagement:

- 19%, reduced cycle time for the large Air Set Floor castings
- Additional foundry floor space of 500 Sq-ft made available due to 5S activities
- Improved utilization of floor space on the mold lines, in the pattern, core room and storage rooms
- An opportunity to increase throughput by 20% by adding a low-skilled support person or "water strider"
- Potential to generate $176,000/yr in revenue provided by increased capacity.
- Improved employee morale and productivity that are the direct result
  - of working in an orderly workspace
  - greater engagement and ownership of the areas
  - visual accounting of WIP/supplies and completed molds.

1.2.2 TECHNICAL PROCESS ASSESSMENT

A two day process assessment was conducted by a Willcor Team expert with extensive experience operating and advising foundries with similar operations. After observing operations and analyzing scrap data the following observations and recommendations were made;

- Two of the SLF mold/casting lines had noticeably higher scrap rates than the others.
- In some cases castings were being handled roughly or while they were too hot and being subjected to thermal shock. Training and greater supervision was recommended to ensure castings were not moved until they had cooled appropriately.
- Exothermic hot toppings were not used on a regular basis to ensure proper feeding from risers. It was recommended that SLF use exothermic hot toppings on a regular basis to reduce defects associated with shrinkage.

- Gas porosity problems and observation of moisture/condensation in some molds was observed. It was recommended that additional gas escape holes be made in molds to reduce gas porosity issues. Mold dryers and other techniques may be needed if these problems persist.

These recommendations are expected to improve quality and reduce scrap rates. They had not been fully implemented as of the end of the project due to the short timeframe for the SLF project. Implementation of these recommendations by the company were in progress as the Willcor Team completed their efforts.

2 IN-DEPTH ANALYSIS AND DISCUSSION:

2.1 Job Shop Lean

2.1.1 Specific Job Shop Lean Analysis and Improvements

2.1.1.1 Air Set Floor Molds

Summary

The Air Set Floor production line produces large size castings ranging in size from 36 Squares to 76 squares using the no-bake molding process. Typical operations in this area include pattern setup, pouring sand, stripping the mold, painting the mold, setting up cores, clamping the mold and pouring the metal. Over a period of 8 weeks, improvement efforts sought to decrease the cycle time and thereby improve throughput determined as the number of molds completed per day, increase the available floor space for both value-added and support activities, and increasing sand mixer utilization.

Current State

In the beginning "as is" state, preparing a combination of cope and drag and closing them in the Air Set Floor area took on average about 77 minutes from start to finish. The process flow chart in Table 1 summarizes a process analysis that was conducted on an Air Set Mold of a 56 x 56 flask size mold. Originally, the process of preparing a mold typically contained 7 delay-causing steps and 9 transportation steps. Both types of activities are non-value adding, waste labor, reduce equipment capacity, block floor space, and therefore were targets for reduction.

Table 1: Flow Process Chart

FLOW PROCESS CHART		
Operation Overview	**Event**	**Present**
Location: Air Set Floor	Operations	8
Activity: Prepare Cope and Drag	Delays	7
Date: 02/18/2010	Inspect	0
	Transport	9
	Storage	2
	Time (min)	77

Table 2 presents a detailed description of the different delays (coded as "D") and transport (coded as "T") operations in the Flow Process Chart of Table 1. This detailed version of the

Flow Process Chart was later used to identify the non-value added activities and prioritize efforts that were made to reduce the cost and non-value added labor content in the overall process. The next section discusses the steps taken to reduce the different non-value added activities.

Table 2: Extension of the Flow Process Chart in Table 1

Event Description	Symbol			Before Time (min.)
	Exceptions	Mode(B)	Mode(A)	
COPE				
Locate Pallet		D		4
Move Pallet to Floor		T		2
Locate Flask		D		3
Move Flask to Floor		T		2
Dry Flask		D		5
Locate Pattern	X	D	D	varies
Move Pattern to Floor	X	T	T	varies
Paint Mold		O	O	10
Locate Risers		D		1
Move Risers to Floor		T		1
Place spills, rods, risers		O	O	3
Place flask on pattern		O	O	2
Remove existing drag from mixture		T	T	2
Place cope under mixture		T	T	2
Fill Sand		O	O	12
Level Sand		O	O	3
Clean Area		O	O	2
Cure Time	X	S	S	26 (varies)
DRAG				
Get Flask		T		5
Clean Flask		D		1
Place flask on pattern		O	O	1
Set Locators/Pins for alignment		O	O	2
Blow air to clean		D	D	0.5
Place Drag Under Mixer		T	T	1
Fill Sand		T	T	12
Cure Time	X	S	S	20 (varies)

A persistent issue/concern that had been raised was the perceived shortage of space for mold preparation in the Air Set Floor area. Observation of this area of the foundry in the Air Set Floor area (see Figures 2-1 and 2-2) showed that much space was wasted because (i) upsets were randomly, placed on the floor and (ii) items categorized as “unnecessary” were being stored in this workspace. The next section discusses the activities that were conducted to reclaim the floor space from these types of non-value added inventoried items in the Air Set Floor area.

Figure 2-1: Upsets lying on the floor

Figure 2-2: Upsets and other supplies in a state of disorganization

Improvements Made

The team started the implementation of Lean by developing a Value Stream Map (VSM) for the entire foundry operation. After confirming that mold preparation was the cycle time driver and the primary determiner of foundry capacity, more process details were obtained on the mold preparation process and supporting operations. This was followed by development of a timeline for the mold making process and identifying non-value added (NVA) activities. Detailed analysis of the Flow Process Flow Chart corresponding to the VSM (see Tables 1 and 2) helped to guide a systematic improvement process. First, a 3-person team conducted 5S activities. This team focused on red tagging and removing unnecessary items. Their activities resulted in the elimination of clutter that immediately freed up 500 ft^2 of floor space. Later, the team installed hooks on the walls to hang upsets and organized them with size numbers, which improved visual management as shown in Figure 2-3. A new shadow board was installed to better organize the tools and resulted in the shadow box seen in Figure 2-5. Also, new wooden racks were installed at a strategic location to store gates, runners and wooden blocks within easy reach by the employees in the Air Set Floor area. Finally, the addition of a new shelf freed up valuable floor space and provides a Point-Of-Use (POU) "supermarket" to store risers, sleeves, filters, domes and other necessary items that are needed for pattern setup shown in Figure 2-4.

Figure 2-3: Upsets stored and labels

Figure 2-4: Points of use system

Figure 2-5: Shadow Box Storage

Additional time studies targeted the mold preparation process to identify and measure the non-value and value added activities. Study charts showed that on average, approximately 15 minutes representing 20% of the mold build time, non-value activities were embedded in the process. Observations demonstrated that operator travel time to obtain risers, sleeves, filters, flasks, pallets and upsets stored away from the in-process mold contributed significant quantities of wasted motion. The re-organizations that support the Point-Of-Use system documented in Figures 2-3, 2-4 and 2-5 was implemented to store supplies required for mold preparation. Post project evaluation shows that assuming an average of 3 molds are prepared every day, the total non-value added time recovered was approximately 45 minutes daily.

Figure 2-6 presents a histogram that compares the Before vs. After times for various activities performed during mold preparation in the Air Set Floor area based on the times shown in Table 3

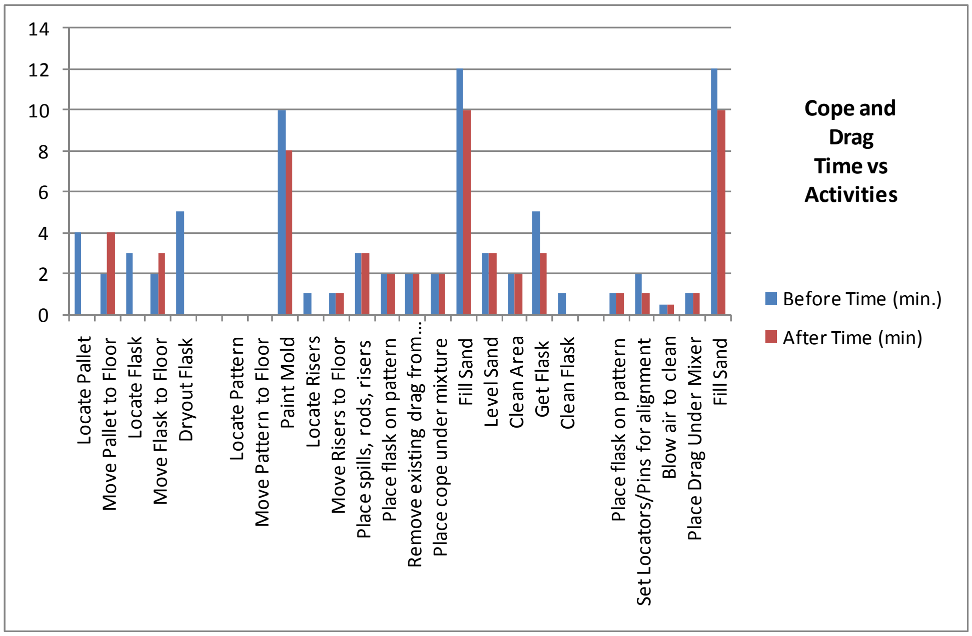


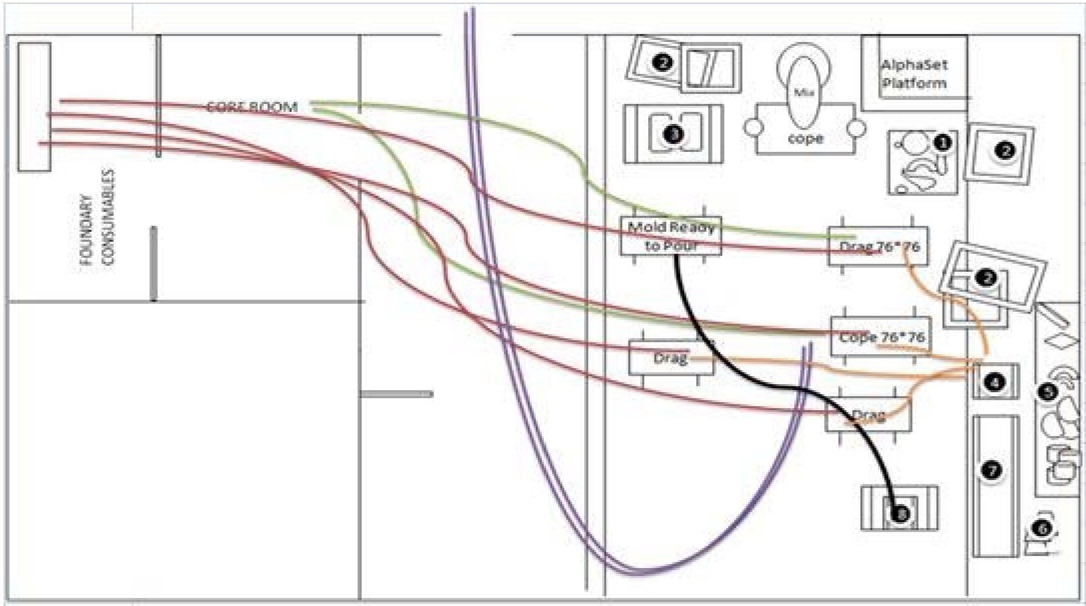
Figure 2-6: Histogram of Cast Operations Time Before and After

which shows the potential time savings to be gained based on analysis of the Process Flow Chart. Although 22 minutes could be saved, we think that at least 15 of those minutes can be value added time (see the column “Recommendation for Method Improvement” in the table).

Table 3: Time Savings Determined by Process Analysis

Event Description	Symbol			Before Time (min.)	After Time (min)	Recommendation for Method Improvement
	Exceptions	Mode(B)	Mode(A)			
COPE						
Locate Pallet		D		4		
Move Pallet to Floor		T		2	4	Stock few pallets at floor
Locate Flask		D		3		
Move Flask to Floor		T		2	3	Stock few flasks on floor
Dryout Flask		D		5	0	Eliminate by stocking under a roof
Locate Pattern	X	D	D	varies		
Move Pattern to Floor	X	T	T	varies		
Paint Mold		O	O	10	8	Use different brush types and sizes
Locate Risers		D		1		
Move Risers to Floor		T		1	1	Move them to the floor
Place spills, rods, risers		O	O	3	3	
Place flask on pattern		O	O	2	2	Place flask close to the job
Remove existing drag from mixture		T	T	2	2	
Place cope under mixture		T	T	2	2	
Fill Sand		O	O	12	10	Use a high-volume sand mixture or a helper
Level Sand		O	O	3	3	"
Clean Area		O	O	2	2	
Cure Time	X	S	S	26		Varies based on temp
Get Flask		T	T	5	3	Stock flask closer to floor
Clean Flask		D		1	0	Eliminate by stocking under a roof
Place flask on pattern		O	O	1	1	
Set Locators/Pins for alignment		O	O	2	1	Store locators close to the job
Blow air to clean		D	D	0.5	0.5	
Place Drag Under Mixer		T	T	1	1	
Fill Sand		T	T	12	10	Use a high-volume sand mixture or helper
Cure Time	X	S	S	20		Varies based on temp

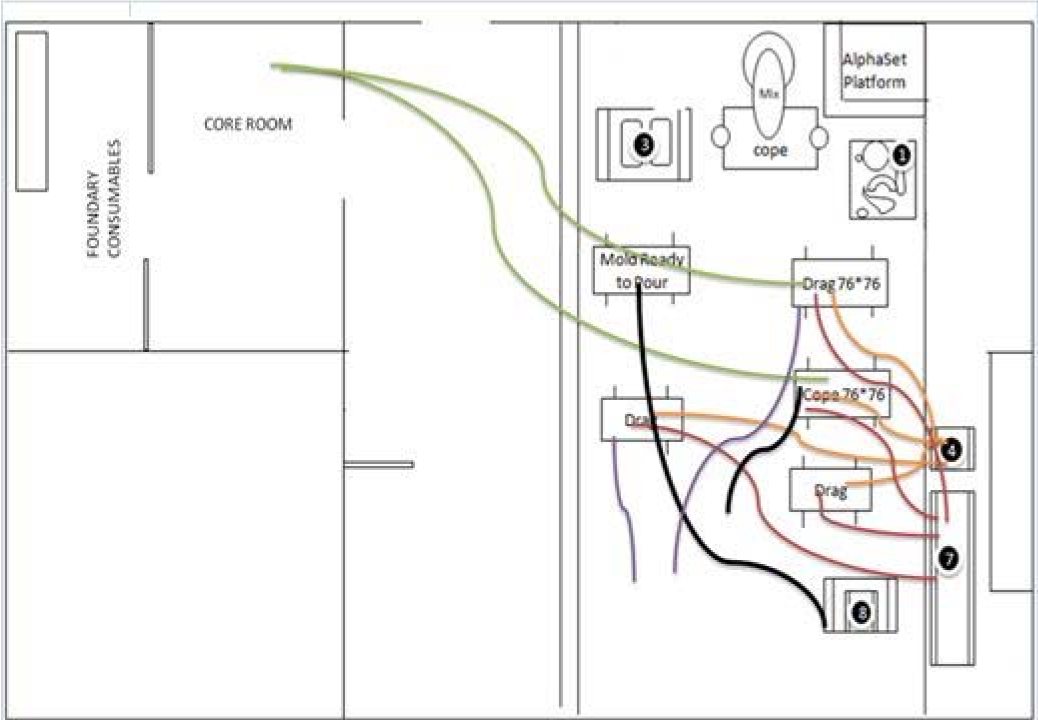
The Spaghetti Diagram in Figure 2-7 shows the workflows in the production area before 5S and complementary improvements in the facility layout, storage options, ergonomics, etc. were made. In contrast, the Spaghetti Diagram in Figure 2-8 shows the modified workflows in the same production area that have been designed and implemented for this foundry.



Number	List of items representing on the floor
1	Runners, Rods, Gates, chills etc
2	Upsets
3	Rogers flat plate with weights
4	Tommy's cabinet with brushes, paint bucket, glue, cope seal and some tools
5	Tools like Hammer, wrench, Grinder, Chills, Sleeves
6	Shift Pins/Locators in Buckets
7	Entire rack with jimmy stuff like runners, gates, risers, upsets etc
8	Pallets of different sizes

COLOR	CODE
	Get Supplies like, Risers, Sleeves, Filters etc
	Get cores
	Get Flasks
	Get Pallets
	Get Auxiliary supplies like cope seal, hammer, paint etc

Figure 2-7 Workflows in the Air Set Floor Production Area before Improvements



Number	List of items representing on the floor
1	Runners, Rods, Gates, chills etc
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3	Rogers flat plate with weights
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5	Tools like Hammer, wrench, Grinder, Chills, Sleeves
6	Shift Pins/Locators in Buckets
7	Entire rack with jimmy stuff like runners, gates, risers, upsets etc
8	Pallets of different sizes

COLOR	CODE
	Get Supplies like, Risers, Sleeves, Filters etc
	Get cores
	Get Flasks
	Get Pallets
	Get Auxiliary supplies like cope seal, hammer, paint etc

Figure 2-8:Workflows in the Air Set Floor Production Area After Improvements

Next, we focused on reducing the non-value adding material handling steps in the mold preparation process. In the Current State, every mold takes 20-30 minutes for the sand to bond and harden after the flask has been filled with sand poured from the mixer. Both observation and analysis of the Process Flow Chart showed this step to be a bottleneck because, at the present time, there is no transfer system that can move the mold away from the mixer immediately after the flask is filled with sand. If this were possible, it would free up space under and around the mixer for the next flask to be brought in, positioned and filled with sand. Due to this constraint, currently there is a wait time of about 20 minutes for the sand in the most recently filled mold to harden before a forklift can lift it and move the mold to another location in the Air Set Floor area. Due to this avoidable delay caused by lack of a more effective material handling system (possibly rollers), the sand mixer with a potential fill-rate capacity of 300 lbs/minute has been underutilized (current average daily utilization is only 10%-15%).

New State

Based on the Process Analysis, several improvements – Point-Of-Use Storage, upsets nested and hung on the walls, chills/pallets/flasks placed close to the work area where molds are being prepared – offer a saving of at least 15 minutes per mold. Figure 2-9 shows the Air Set Floor area after completion of all 5S and other improvement activities. Using Activity Based Costing, assuming that the 15 minutes saved per mold in the Air Set Floor area could be utilized to prepare more molds, an additional $192,000 in additional revenues could be generated due to this increase in throughput.

Figure 2-9: Additional Floor Space in Air Set Floor after 5S

An additional recommendation was to add a helper/water strider to support employees currently working in the Air Set Floor area. This is because the Cost vs. Benefits Analysis showed that this could increase the throughput (# of molds prepared) by 20%, from 8 molds/day to 10 molds/day; in turn, this could generate extra revenue of $176,000/yr. By similar calculations, if the throughput could be improved to 12 molds/day, then the extra revenue per year that could be generated by the Air Set Floor area alone would be $576,567.

A final recommendation was that SLF look for sand mixers with articulated arms that can fill flasks without needing a forklift to move flasks to the mixer and remaining there until the flask was filled with sand. This would reduce material handling costs and prevent potential injury to employees due to the forklift truck operating in their workspace.

Key Results

There were four key results that came from the JSLean activities at SLF:

- Reduced non-value added activities by 20% thereby reducing material handling costs.
- Additional floor space of 500 Sq-ft due to 5S activities.
- Opportunity to increase throughput by 20% by adding a water strider which could generate $176,000/yr in revenue.
- The intangible benefits to be gained are improved employee morale from working in a clean and orderly workspace, greater engagement and ownership of the areas (possibly resulting in reduced damage to molds), visual accounting of WIP/supplies and completed molds.

2.1.1.2 Pattern Room and core room

Summary

For the Pattern Room, the project effort was divided into two phases: The first phase involved analyzing pattern use data for 2008 and 2009. For each of the years (2008 and 2009), the datasets consisted of columns for Part Number, Pattern Location, Molding Section, Order Quantity and Flask Size. After analyzing the data using MS Access and MS Excel, the resulting dataset showed the high-running patterns respective to each molding line for both years. Figure 2-10 shows a Pareto Chart for the patterns used in Air set Floor area. Similar Pareto Charts were created for other molding sections in the foundry.

The second phase of the project involved organizing the Pattern Room. The team at the “Maritime Cast Shop” led this effort by (i) red tagging all the unused patterns that had never been run in the last 5 years or the patterns which had *never* been run, and (ii) organizing the Pattern Room based on the usage data provided after the first phase of the project.

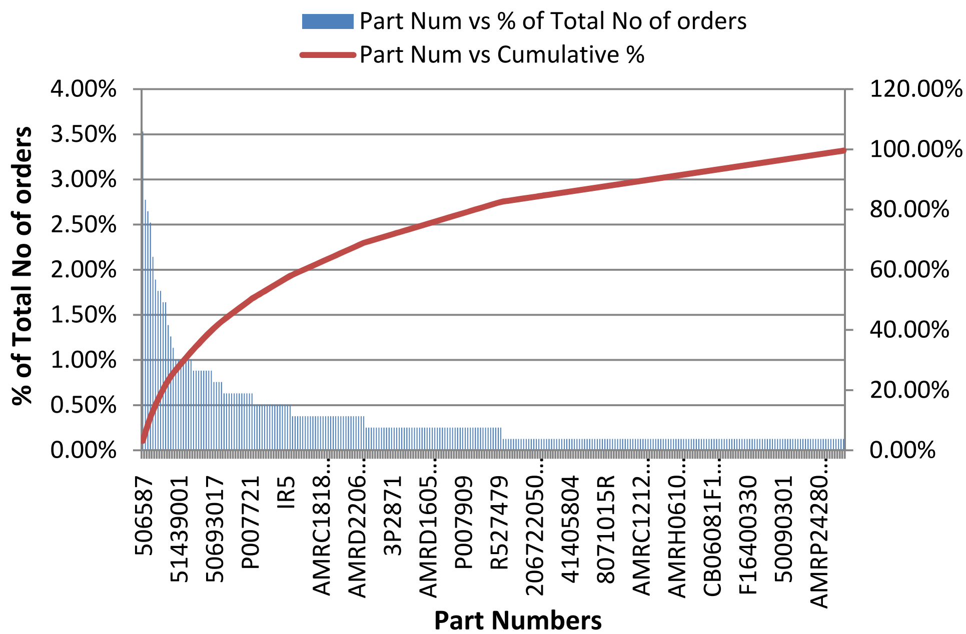

Figure 2-10: Pareto Chart on Air Set Floor Patterns

The Core Room project involved identifying strategic locations to store cores and core-boxes coupled with design and implementation of a visual management system for storage/retrieval. This short-term improvement project was very well executed by the project team. The Core Room now has a rack in a strategic location for storing small-size cores, with the core-boxes being labeled with their Part Numbers. Also, a separate storage location has been designated for the metal core-boxes that have been used by the injection molding machine and a labeling system devised to enable tracking of all active core-boxes.

Current State:

In its Current State, the Pattern Room has many patterns that were never run at the foundry. These unused patterns occupy considerable floor and cube (vertical) space which, if freed up, would provide significant storage space for pattern storage. Currently there are different locations for pattern storage. And, while some have a tracking system and designated storage locations on existing shelves, others are kept at different locations spread throughout the premises without any tracking system. The result is that one, often more, employees spend significant amount of their day in "Operator Motion" waste i.e. searching for a pattern that has been scheduled for mold preparation. At times, it has taken days to track a pattern.

In its Current State, the Core Room has no shelves to store cores and core-boxes. Everything is kept on the floor in a disorderly fashion which, invariably results in non-value added work, due to increased material handling, labor time spent in shifting, searching, etc. and, in the worst case, damage to cores.

Improvements made:

Analysis of the pattern usage data generated 6 different spreadsheets corresponding to each of the six molding lines. Each spreadsheet sorted the part Numbers by decreasing usage volume. Pareto Analysis for each year (summarized in Figure 2-10 above) corresponding to a molding section showed that, in both years 2008 and 2009, at most only 20% of the patterns were high frequency "runners" and the remaining (80%) of the patterns are slow-to-medium frequency "repeaters and strangers."

Table 4 shows a sample data set containing Part Numbers in the Air Set Floor area that are the "runners" in 2009. The column "Number of Orders", which was sorted in descending order, shows the frequency of orders greater than 6. This table can be linked to the Pareto Analyses to see the top 20% of the part numbers which contribute to around 80% of the total number of orders processed by SLF.

Table 4: Sample data for pattern usage in Air Set Floor area for 2009

Part Number	Tot Qty	Num of Orders	Customer	Part_No	Flask_Size	Patt_Loc
505569	31	15	Eaton	505569	60x60	Marine Building
506587	41	14	Eaton	506587	54x54	Marine Building
513394	39	13	Eaton	513394	48x48	Marine Building
RF364172P1	26	13	Rolls Royce	RF364172P1	54x54	Marine Building
506930	21	12	Eaton	506930	40x40	Garage
506587	25	12	Eaton	506587	54x54	Marine Building
50620114	17	11	Eaton	50620114	54x54	Marine Building
C06N080701	129	10	Fairfield	C06N080701	44x56	Marine Building
51450801	18	9	Eaton	51450801	60x60	Marine Building
9219746G	19	9	Cotta	9219746G	44x56	Marine Building
C06N080703	127	9	Fairfield	C06N080703	24x34	Marine Building
50620114	9	8	Eaton	50620114	54x54	Marine Building
RRE030736	14	8	Rolls Royce	RRE030736	50x70	Marine Building
8071020R	225	8	Durst	8071020R	36x36	Marine Building
512812	29	7	Eaton	512812	60x60	Marine Building
513138	27	7	Eaton	513138	54x54	Garage
513318	29	7	Eaton	513318	40x40	Rack 33
514218	17	7	Eaton	514218	54x54	Marine Building
51454201	17	7	Eaton	51454201	60x60	Marine Building
C06N080701	91	7	Fairfield	C06N080701	44x56	Marine Building
302TLS151	45	7	Gardner Denver	302TLS151	50X70	Garage

The second phase of the project started in parallel with the first phase. The "Maritime Cast Shop" team is working on red tagging those patterns that were *not used at all* in the past 5-6 years then contacting those customers to ask whether they should obsolete/return the pattern/s or keep the pattern "alive".

In addition, the Core Room has seen improvements in material handling. Figure 2-11 shows the room after completion of preliminary 5S activities. Employees report that they are spending less time looking for, picking and kitting, and moving cores in the Core Room. Unfortunately, due to time limitations, a detailed time study and Flow Process Analysis (similar to what was done for mold preparation in the Air Set Floor area) could not be conducted to develop a representative timeline for the process of moving a core. This analysis would have helped to clarify and validate cost reductions (especially due to material handling) and labor time savings already achieved from other projects executed at SLF.

Figure 2-11: Core Room with New Shelf Storage and Labels for Identification of Cores and Core Boxes

New State:

The improved core room storage system is complemented by a visual tracking system which consists of core box pattern numbers being logged on sheets that are attached to the shelves.

Additional opportunities to increase floor space and handling of cores and core-boxes in the Core Room using simple 5S-type ideas are being explored. For example, instead of its current position where it is facing the wall, the sand mixer head will be rotated by 180 degrees to face the jib crane. This will reduce the travel time required to fill big core-boxes that were filled with buckets, with the jib crane being used later to strip the core. This will dramatically reduce material handling time.

The Pattern Room project is an ongoing 5S project at SLF with the foundry's team locating the patterns which are the high-volume "fast runners" upfront near the entrance and the low-volume "slow runners" deeper towards the rear of the room. In addition, a "supermarket" for storage of patterns for each day, and maybe the next day, should be strategically located on the production floor (near the Air Set Floor area) with labeled racks as part of a visual management to move patterns in and out of the Pattern Room. These would be organized based on the frequency of the jobs and expected usage. Finally, it is urgent that the "Maritime Case Shop" employ numerical metrics (**Examples:** Number-of-moves from sand mixer to the core box, % non-value added time involved in preparing a core, Number of man hours utilized to prepare cores for different core box sizes) to motivate the workforce and prioritize actions taken by the management team responsible for implementing and sustaining Lean in this foundry job shop.

Key Results:

- Improved material handling in the Core Room by reducing non-value added time in the workflow processes for moving cores and core boxes.
- Re-organized the Pattern Room by using Pareto Analysis to segregate the active patterns into “fast runners” and “slow runners” as a basis for deciding which patterns ought to be stored closest to the entrance/exit of the room and ease of access for storage/retrieval at short notice.
- Freed up valuable storage space in the Pattern Room by red tagging the unused patterns and communicating with customers whether they would take them back, or should be retained due to projected demand for those castings.

2.2 Technical Process Improvements Based on the Cast Shop Floor Assessment

2.2.1 Broken Castings

Observation

A number of castings were observed to be broken or cracked on the foundry floor. The direct cause of these broken and cracked castings was attributed to rough handling and thermal shock experienced by the casting during the shake out process. Figure 2-12 is an example of a casting stripped out of its mold too early. The casting was too hot to be shaken out of the sand. A casting that is too hot when stripped from the mold has not developed sufficient mechanical stress to withstand handling operations. Additionally, a casting stripped while too hot develops high thermal stresses due to the increased cooling rate of a hot casting in air. High thermal stresses exacerbate the condition of low mechanical strength.

Figure 2-12: Handling of Hot Castings

Best Practices

Newly solidified castings with temperatures 1700F or hotter, have low mechanical strength. They will fracture and break if handled with the tongs or the bucket on the loader. Castings should remain in the mold undisturbed until they cool to temperatures lower than those that produce the red heat color, approximately 1500F, to prevent defects as described in this section.

If they must be moved, to make room on the casting floor for subsequent mold set-ups, place them aside and strip them much later, preferably during the next shift

Recommendation

Assign the shop floor supervisor the responsibility to monitor and control the shake out of casting.

Train supervisors and critical shop personnel in the core principles of the relationship between mechanical strength and casting temperature as well as the relationship between internal thermal stresses and cooling rates.

2.2.2 Flow Interruptions During the Pour

Observation

The current planning process for a pour may lead to interruptions during this critical operation.

Flow interruptions of the molten metal as it is transferred from the ladle into the mold results in a discontinuity in the surface of the casting. A very thin layer of oxide instantaneously forms between the two poured layers of metal. A permanent defect is the result.

The planning process for each heat should provide ample time for pouring the desired volume and number of castings. Currently, the shop process is to measure temperatures

Figure 2-13: Temperature measurement of ladle

of a melt with an immersion thermocouple (Figure 2 -13) and recorded on the work sheet.

Of note is the high process risk that exists for the last ladle tapped from the furnace. Typically the molten metal is on the low end of the specified temperature range. It is highly likely that cold metal will be added to one or more of the last castings in the series to be poured.

Best Practices

Each pour should be planned and monitored such that the possibility of pouring cold metal is minimal. Molten metal temperatures should be sufficient to remain within the specified range during the pour and the volume of molten metal should be sufficient to complete the number of molds in the series.

The good judgment of the supervisor during the taping and pouring processes in a foundry are essential to success. Supervisory personnel should be present and active during the pouring of each casting.

Recommendation

Review foundry processes and ensure that best practices concerning temperature and volume are included. Ensure floor supervision is integral to these processes.

2.2.3 SAND INCLUSIONS:

Observation

Sand Inclusions are typically caused by faulty gating systems, erosion of sand molds during pouring, break-off of portions of the sand mold caused by turbulent flow, and even loose sand in the mold cavity resulting from assembly of the mold. Experience as well as the Data reviewed during the assessment period indicates that the occurrence of sand inclusions is a recurring problem in green sand castings. These critical casting defects are a consequence of two common issues.

The first cause of sand inclusions is a direct result of the mold design. A defect caused by the mold design is recurring. If sand inclusion defects are in a similar location in an identical series of molds, it would be expected that the problem is caused by the design of the mold. Technical expertise in examining new mold patterns should enable the designer to spot this potential problem and resolve it.

Random sand inclusion issues are the result of mold preparation and handling issues. Rough handling and/or poor molding techniques are typical causes of random sand inclusion flaws.

Best Practices

Supervision associated with mold assembly is the best approach to identifying these problems and when a sand inclusion defect occurs, a meeting of mold makers as well as ladle man/casters needs to be held so that supervisors can explain to all involved what the problem is and how it can be remediated. A closed loop failure analysis process is an essential best practice.

Recommendation

A short weekly team meeting is recommended to discuss the casting defect highlight of the week wherein it would be stated as to how many defects of the specific type were found, how much material was scrapped by this defect and how the situation would be improved. This would provide the closed loop process needed. A follow-up in the next meeting or as soon as possible would show how the planned action had been implemented and improvements noted. This type of action requires problem solving on the part of both supervisory and operating personnel. A chart/illustration (including photos, if possible) on a weekly/daily production bulletin board showing the weekly problem and the corrective action taken is suggested.

Solicit suggestions from both supervision and operating personnel on how the team can change or modify procedures to minimize or eliminate the problem under consideration. Visual Management charts, graphs, and pictures provide a constant reminder to all personnel of quality success.

2.2.4 Gas Porosity

Observations

Gas porosity was observed on the surface of some castings as shown in Figure 2-14.
A leading cause of gas porosity is the improper de-oxidation of the metal in the furnace, Observations of the furnace practices for two days as well as the metal in the ladles during pouring of the casting indicated that acceptable de-oxidation practices were routinely used.
Surface gas porosity can also result from moist sand being used in the mold process or

Figure 2-14: Evidence of Moisture in an Air Set Mold Casting

from metal that reacts during the pouring process. This is generally true for both green sand molds and Air Set sand molds. The above photo (Figure 2-14) of an Air Set mold that had been recently cast shows evidence of moisture or condensate in crack areas, most likely caused by entrapped gases and/or the condensation of moisture.

Best Practice

Porosity from moist sand or reacting metals is frequently eliminated by creating gas escape holes in the Air Set sand mold. This step should be integrated with the sand compaction process. Gases will escape though these holes and typically ignite and burn which suggests that the gases escaping contain combustible hydrogen. The use of gas venting assures an improved surface on the casting due to the lack of surface gas porosity.

Recommendation

Ensure that gas escape holes are integrated into the mold building processes.

2.2.5 HOT TOPPING

Observations

During the two day observation period at SLF, hot topping (using exothermic hot topping compound) of molds was used infrequently. The principal use of hot toppings was on the larger Air Set molds. Rarely was hot topping used on the smaller green sand molds.

A practice of breaking off a small portion of the green sand molds after they had been filled and placing the crumpled sand on the mold's riser as a pseudo-hot top was used. It may have provided a small amount of insulation to the riser, but did not perform as an exothermic hot top and did not introduce any thermal energy to the surface of the riser.

The use of an exothermic hot topping compound ensures the proper feeding of the mold during the pouring process. Hot topping reduces the potential for shrinkage defects and pull down or formation of concave surfaces on the casting.

Best Practice

To provide consistency in casting practice, small plastic bag containing a measured amount of exothermic compound are added to each riser on castings. For larger castings with larger risers and longer solidification times, it may be necessary to add more than one bag of hot topping material. This practice ensures the proper feeding of the solidifying casting from all risers and minimizes internal casting defects associated with shrinkage. The hot topping practice helps alleviate pull down or formation of concave surfaces on the casting.

Recommendation

Ensure that hot topping processes are integrated into the mold building processes

2.2.6 RUN OUT

Observations

A green sand mold experienced a run-out as shown in the photo, Figure 2-15.

Figure 2-15:Mold Run Out

It appears as the leak of molten metal occurred between the cope and drag portions of the mold. It was observed that the ladle man continued to pour metal into the mold. The leak froze off. In all probability, the casting made was faulty and ultimately discarded.

There did not appear to be any shop floor procedure to identify this particular casting or follow it to assure its acceptability.

Figure 2-16 shows porosity that was observed in a casting after it had undergone grit blasting and cleaning. The porosity perforated the wall of the casting. This cast was one of about 25 identical castings and the only one that showed a defect which suggests that something different (a shortcoming) occurred in the pouring/casting procedure of this particular part.

Figure 2-16: Through Wall Casting Defect

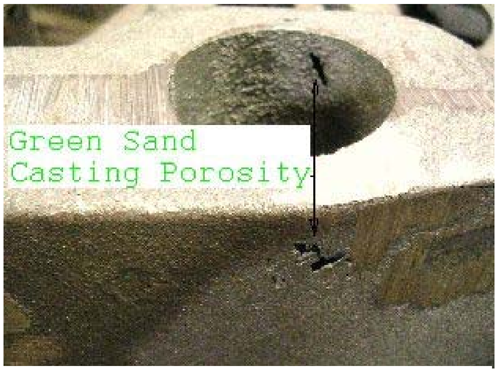

Figure 2-17: Close up of Through Wall Casting Defects

Figure 2-17 is a close-up of the same casting rotated 90 counter-clockwise. It shows the same defect and a second defect in the bore through the center of the casting. It is postulated that both defects were caused by metal being too cold when flowing to fill the mold cavity. Both defects perforated the casting thickness near the core. The cause of this defect is that the core may have served to chill the metal and diminished its ability to flow.

Best Practice

A closed loop follow quality process is required to identify issues as they are observed to that supervisory personnel can follow up on cast component potential deficiencies.

Continuous processes tools such that identify failures modes and effects are critical element of continuous improvement processes found in effective operations.

Recommendation

Institute a closed loop quality process that cast floor personnel can easily access.

Institute a process that identifies failure modes and implements corrective process actions. Both of the above processes should start with the direct supervisor on the pouring line.